AFRL-ML-WP-TP-2004-413

MILITARY AEROSPACE FLUIDS AND LUBRICANTS WORKSHOP PROCEEDINGS

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Nonmetallic Materials Division
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Air Force Research Laboratory, Air Force Materiel Command
Wright-Patterson Air Force Base, OH 45433-7750

NOVEMBER 2004

Final Report for 15 June 2004 – 17 June 2004

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STINFO FINAL REPORT

MATERIALS AND MANUFACTURING DIRECTORATE
AIR FORCE RESEARCH LABORATORY
AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-7750

NOTICE

This technical report has been reviewed and is approved for publication.

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REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
November 2004	Final	06/15/2004 – 06/17/2004

4. TITLE AND SUBTITLE
MILITARY AEROSPACE FLUIDS AND LUBRICANTS WORKSHOP PROCEEDINGS

5a. CONTRACT NUMBER In-House
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER 62102F

6. AUTHOR(S)
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5d. PROJECT NUMBER N/A
5e. TASK NUMBER N/A
5f. WORK UNIT NUMBER N/A

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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Wright-Patterson Air Force Base, OH 45433-7750

8. PERFORMING ORGANIZATION REPORT NUMBER
AFRL-ML-WP-TP-2004-413

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
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Air Force Materiel Command
Wright-Patterson AFB, OH 45433-7750

10. SPONSORING/MONITORING AGENCY ACRONYM(S)
AFRL/MLBT

11. SPONSORING/MONITORING AGENCY REPORT NUMBER(S)
AFRL-ML-WP-TP-2004-413

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; release is unlimited.

13. SUPPLEMENTARY NOTES
Report contains color.
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This technical paper is comprised of numerous PowerPoint slideshows that were presented at the workshop.

14. ABSTRACT
The Military Aerospace Fluids and Lubricants Workshop was presented by the Materials and Manufacturing Directorate of the Air Force Research Laboratory in order to disseminate information about military lubricant changes and related issues. Major topics included hydraulic fluids: conversion of aircraft from MIL-PRF-5606 to MIL-PRF-87257, system seals, actuator rod tests, T.O. 42B2-3-1 revision status, DoD contamination issues, elimination of storage fluids for hydraulic components, condition monitoring,. Also topics of the workshop were gas turbine engine oils: R&D, test methodology and future trends. Lastly, the topics of the workshop presented were greases: R&D, problem solving and evaluation of MIL-PRF-32014.

15. SUBJECT TERMS
fire resistant hydraulic fluid, military hydraulic fluid, fluid purification, red oil, synthetic hydrocarbon, polyalphaolefin, aerospace hydraulic fluid, gas turbine engine oil, military grease

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT:	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON (Monitor)
a. REPORT	b. ABSTRACT	c. THIS PAGE			Carl E. Snyder, Jr.
Unclassified	Unclassified	Unclassified	SAR	778	19b. TELEPHONE NUMBER *(Include Area Code)* (937) 255-9036

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18

AGENDA

15 June 2004

Session I Hydraulics, Ed Snyder Chair

0800 – 0815	**Welcome and Introductory Remarks** *Col. Timothy Sakulich, Deputy Director, Materials and Manufacturing Directorate, Air Force Research Laboratory, WPAFB*
0815 – 0845	**Overview,** *Ed Snyder, AFRL*
0845 – 0915	**AF Lubricant Specs & Conversion,** *Lois Gschwender, AFRL*
0915 – 1015	**Re-oiling in the German Air Force** - Status of GAF future fleet reduction - Results of Cold Soak Flight Trials, Dec 2002 - Decision pending on future usage of H537/H538 *Wolfgang Frey, Frank Weber and Dieter Bendowski*
1015 – 1030	**Break**

AGENDA

15 June 2004

Session I Hydraulics, Ed Snyder Chair

1030 – 1100 **New O-Ring Material,** ***Al Fletcher, AFRL***

1100 – 1145 **NAVAIR PAX NAS Hydraulics Liaison Report,** ***Jeff Gribble, Naval Air Warfare Center***

1145 – 1215 **Future Trends in Flight Control Actuation,** ***Raymond Levek, The Boeing Co.***

1215 – 1330 **Lunch**

AGENDA

15 June 2004

Session II Hydraulic Fluid Contamination, Shashi Sharma Chair

1330 – 1400	**Future Trends in Flight Control Actuation,** *Raymond Levek, The Boeing Co.*
1400 – 1410	**BSN Hydraulic Fluid Contamination Overview** *Shashi Sharma, AFRL*
1410 – 1440	**Elimination of Barium Containing Fluids in DoD Aircraft Systems, Program and Static Tests** *Lois Gschwender, AFRL*
	Pump Tests, *Shashi Sharma, AFRL*
1440 – 1500	**Break**
1500 – 1530	**Aircraft Fluid System Health Monitoring** *Gary Rosenberg, PALL Corporation*

AGENDA

15 June 2004

Session II Hydraulic Fluid Contamination, Shashi Sharma Chair

1530 – 1600 **Lubricant Cleaning and Compatibility Study for Candidate Chlorofluorocarbon and Hydrochlorofluorocarbon Solvent**
Marcie Roberts, Univ. of Dayton Research Institute
Ed Snyder and Lois Gschwender, AFRL

1600 – 1615 **Oxygen Sensor Development for Fuel Tanks,**
Ed Snyder, AFRL

AGENDA

16 June 2004

Session III Turbine Engine Lubrication
Session Chair: Lewis Rosado, AFRL, Propulsion Directorate

0800 – 0830	**Lubrication for Gas Turbine Engines,** *Nelson Forster, AFRL*
0830 – 0900	**Research and Development of Optimal Ester Turbine Engine Lubricant,** *Lynne Nelson and Lois Gschwender, AFRL*
0900 – 0930	**Oil Development Strategy for High Performance Gas Turbines,** *Lynne Nelson, AFRL*
0930 – 1000	**MIL-PRF-23699 Gas Turbine Oil,** *John Shimski, Naval Air Warfare Center*
1000 – 1015	**Break**

AGENDA

16 June 2004

Session III Turbine Engine Lubrication

Session Chair: Lewis Rosado, AFRL, Propulsion Directorate

1015 – 1045 **Future Propulsion System Mechanical Considerations**
Curt Genay, Ron Yungk, Bill Ogden and Herb Chin, Pratt & Whitney

1045 – 1100 **Seals for HTS Oils,**
Al Fletcher, AFRL

1100 – 1145 **Gas Turbine Engine Oil Anti-wear Additives for Advanced Bearing Steels, SBIR Contracts**
- **1100-1122** *Vern Wedeven, Wedeven Associates*
- **1122-1145** *Rich Sapienza, METSS Corp.*

1145 – 1200 **Engine Oil Condition Monitoring,**
Robert Kauffman, Univ. of Dayton Research Institute

1200 – 1315 **Lunch**

AGENDA

16 June 2004

Session IV Maintainer Issues, MSgt Kurt Hinxman Chair

1315 – 1645	**Topics include:** **Hydro AFSC Training/CEETP,** **HCT-20 Test Stand,** **Hydraulic Fluid Purification/Recycling,** **Landing Gear Strut Servicing,** **Aerospace Hoses Discussion**
1645	**Adjourn**

AGENDA

17 June 2004

Session V Hydraulic Fluid Purification
Session Chair: Lois Gschwender, AFRL

0800 – 0915	**USAF Hydraulic Fluid Purification Program,** *Chief Durkee, Carolyn Tucker, Alan Herman, George Fultz and Ed Snyder*
0915 – 0935	**Effect of Purification on Fluid Properties and Performance,** *Shashi Sharma, AFRL*
0935 – 1000	**Columbia Helicopters Hydraulic Purification,** *Robert Peterson, Columbia Helicopters, Inc.*
1000 – 1015	**Break**

AGENDA

17 June 2004

Session VI Hydraulic Fluid/Pump Condition Monitoring
Session Chair: Lois Gschwender, AFRL

1015 – 1045	**Malabar International Purification Briefing,** *Dave Sweeetland, Malabar International, and Bert Jacobs, Warner-Robbins AFB*
1045 – 1115	**In-line Hydraulic Fluid Contamination Multi-sensor,** *Brad Grunden, METSS*
1115 – 1145	**In-line Health Monitoring System for Aircraft Hydraulic Pumps,** *Shashi Sharma, AFRL* *Bruce Pilvelait, Creare, Inc.*
1145 – 1300	**Lunch**

AGENDA

17 June 2004

Session VII Aerospace Greases
Session Chair: Shashi Sharma, AFRL

1300 – 1330	**Aerospace Greases - Background,** ***Ed Snyder, AFRL***
1330 – 1400	**Alaska Airline Flight 261 Investigation of Lubricating Grease,** ***Jeff Kolly, National Transport Safety Board, and Todd Standish, Naval Air Warfare Center*** ***Presented by Ed Snyder***
1400 – 1430	**Multipurpose, Moisture Resistant, High Load Carrying, PAO Based Grease, MIL-PRF-32014** ***Lois Gschwender, AFRL***

AGENDA

17 June 2004

Session VII Aerospace Greases
Session Chair: Shashi Sharma, AFRL

1430 – 1500	**The Lubrication Solution to C-5 Landing Gear Wear and Corrosion Problems** ***Dave Marosok, Hill AFB, UT***
1500 – 1600	**Discussion/Open Items**
1600	**Adjourn**

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Military Aircraft Hydraulic Fluids and Lubricants Workshop

Welcome and ML Overview

15 June 2004

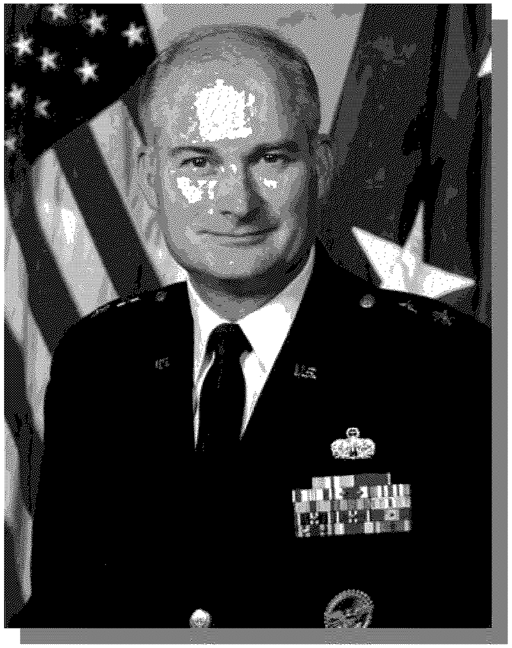
Col Timothy J. Sakulich

Deputy Director

Materials & Manufacturing Directorate

Air Force Research Laboratory

Air Force Research Laboratory



Major General Paul D. Nielsen
Commander

10 Technology Directorates

Air Vehicles Directorate	Materials & Manufacturing Directorate
Space Vehicles Directorate	Directed Energy Directorate
Munitions Directorate	Human Effectiveness Directorate
Sensors Directorate	Information Directorate
Propulsion Directorate	AFOSR

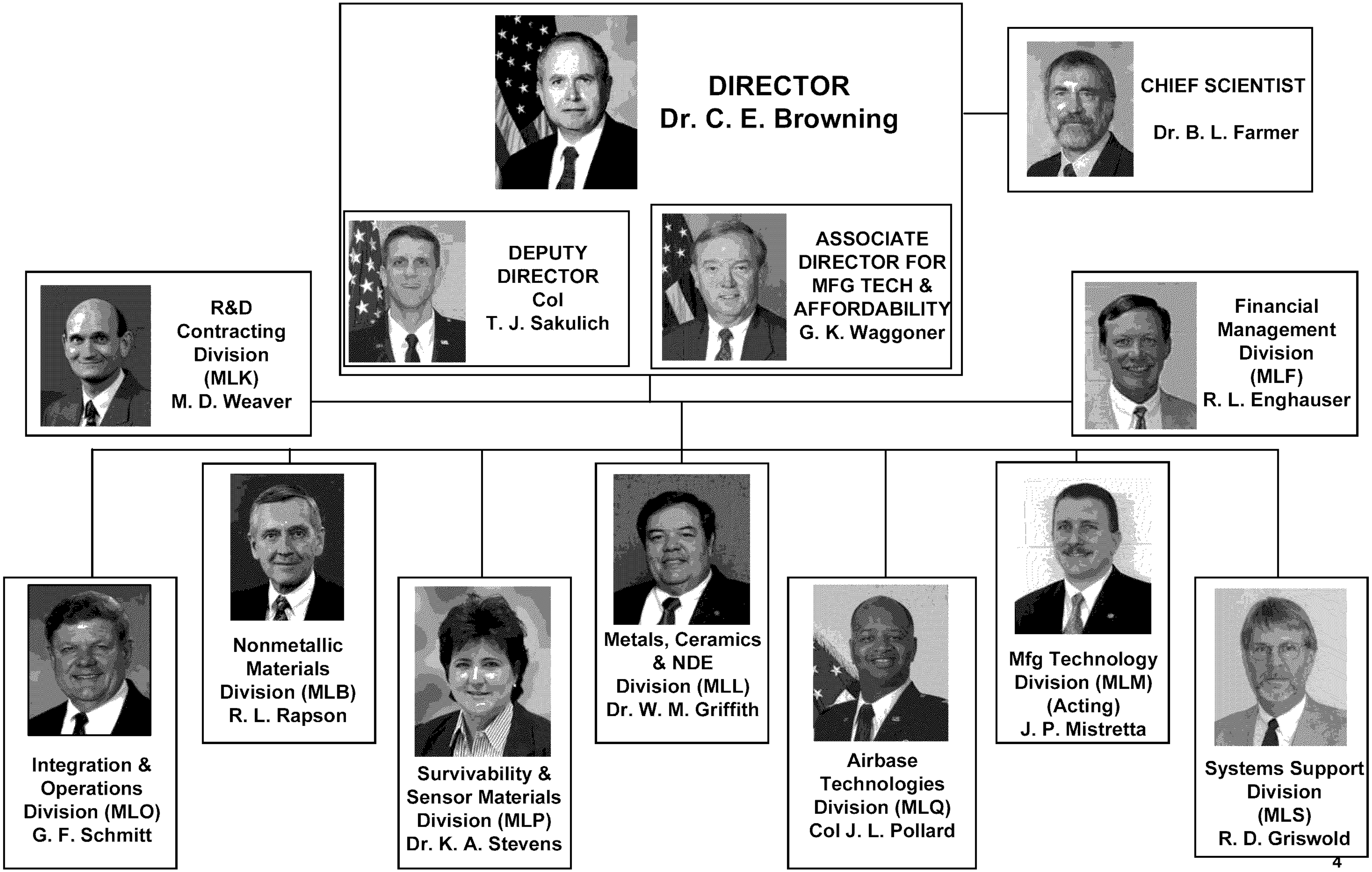
Facts and Figures

- 5266 government personnel
  - 4106 civilian
  - 1160 military
- 3198 on-site contractors
- $1.6B annual S&T budget
- $1.5B annual customer budget

As of Jan 04

ML Mission / Vision

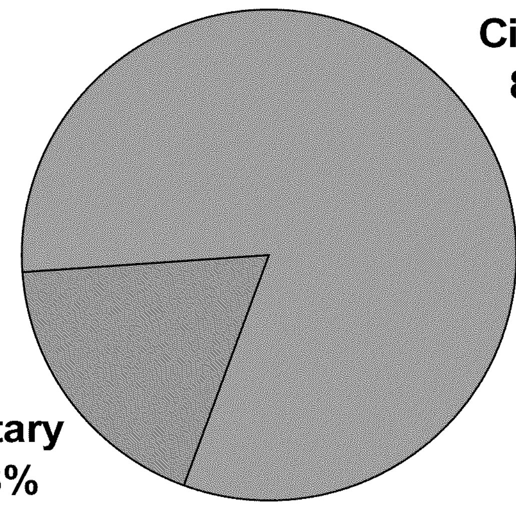
AFRL/ML Organization



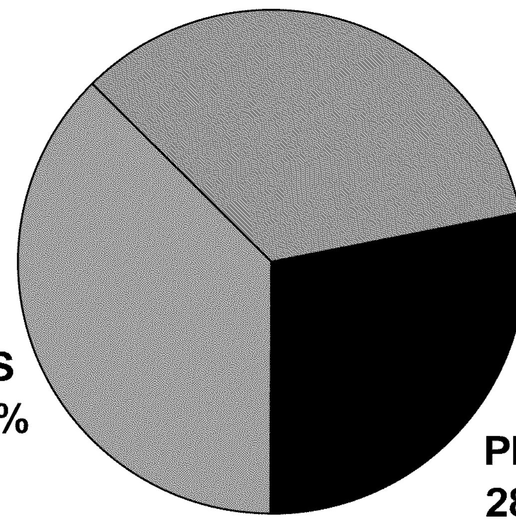
4

Materials & Manufacturing
Personnel

Government	551
IPAs	5
On-Site Contractors	705
Total	1,261



Government (551)

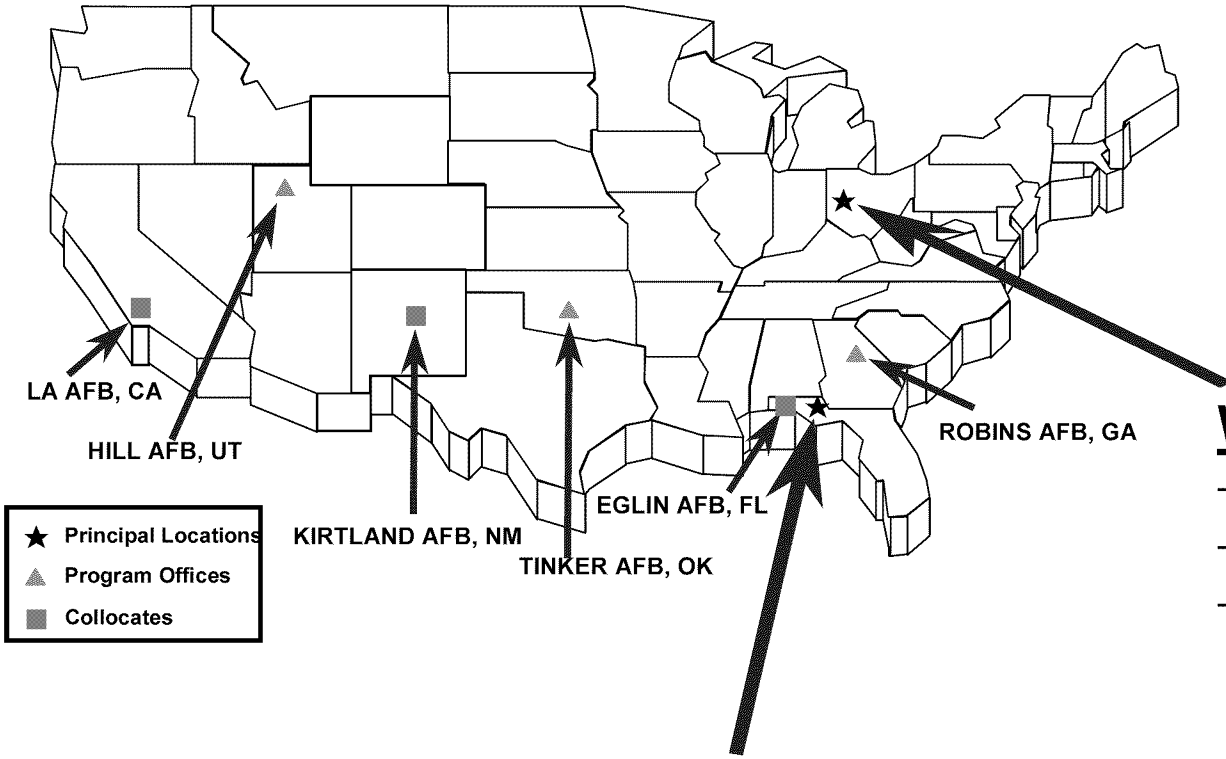


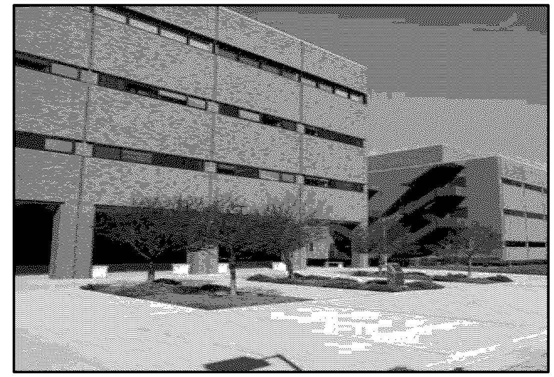
S&E (429)

As of 31 Jan 04

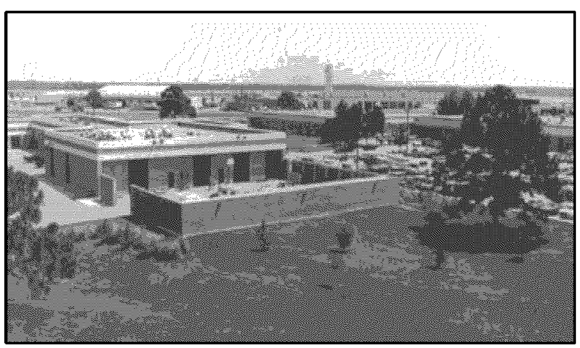
5

Locations & Facilities



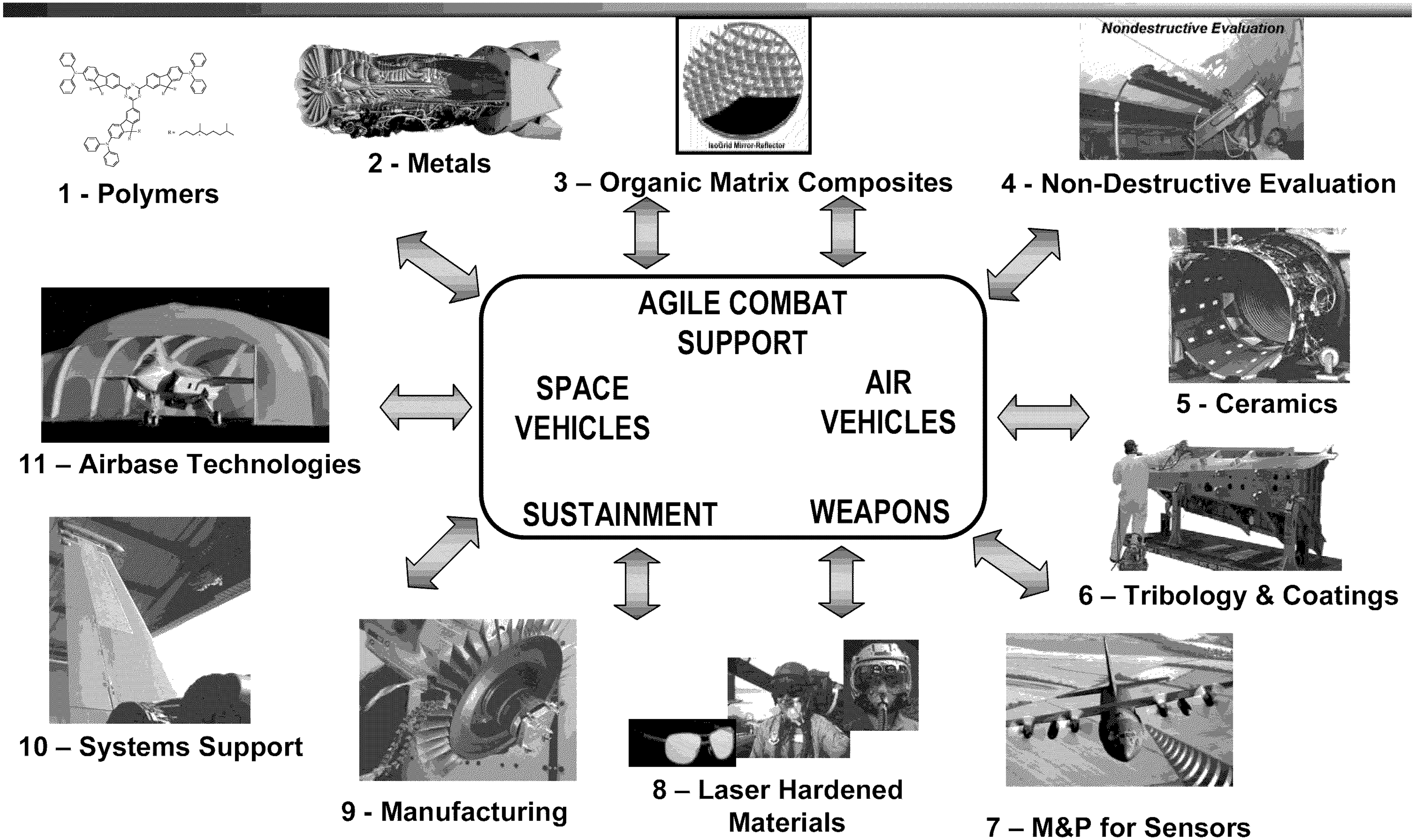


Wright-Patterson AFB
- 257,000 net square feet
- 200 Lab Modules
- Designed specifically for aerospace materials and processes R&D



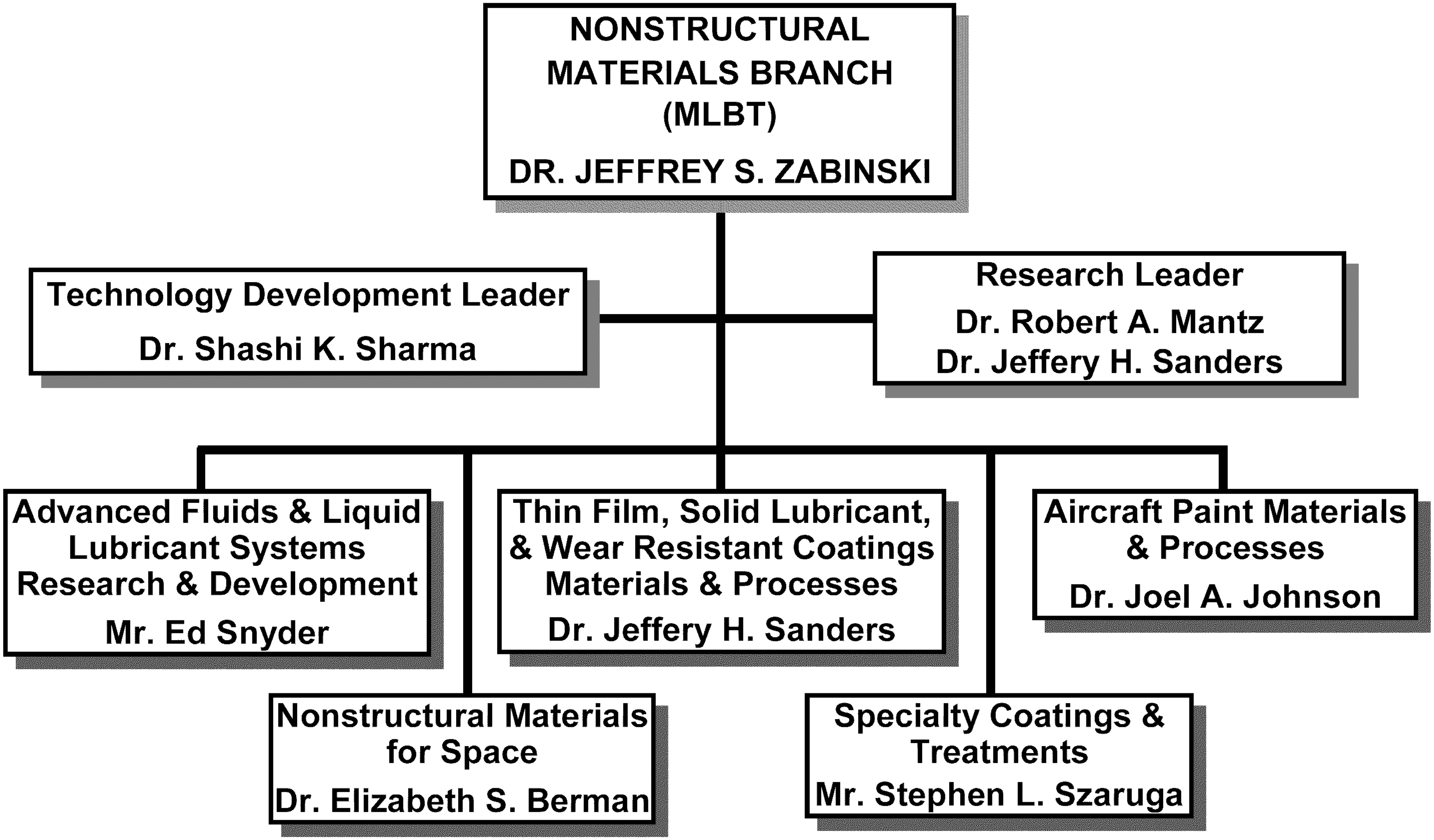
Tyndall AFB
- 128,000 net square feet
- 15 Lab Modules
- Specialized test sites
- Designed specifically for airbase technologies R&D

Technical Program Structure & Integrating Application Areas



Pervasive Enablers to Air and Space Capabilities

Nonstructural Materials (MLBT) Organization



8

Nonstructural Materials (MLBT) Mission

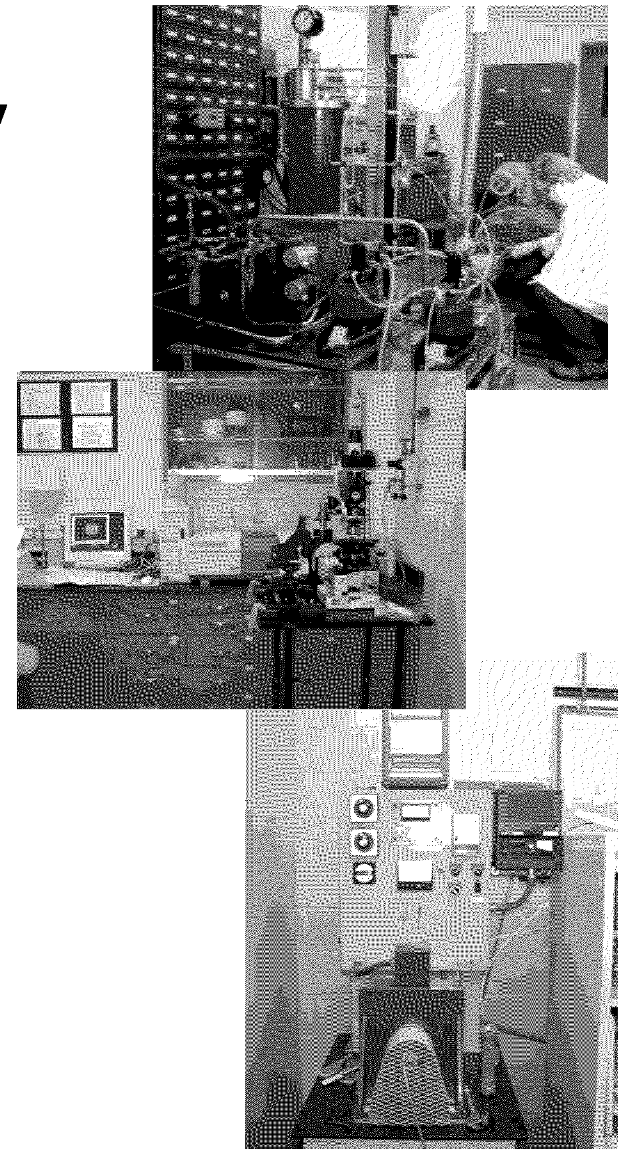
- Advanced nonstructural M&P
  - Extend life
  - Improve performance
  - Enhance survivability
- Advanced tribomaterials
- Nonstructural materials for space
- Aircraft coatings
- Operational system support

MLBT Fluids and Lubricants Group

- Interdisciplinary team of mechanical and materials engineers
- Long heritage in fluids and lubricants research, development and technology transition

MLBT Fluids and Lubricants Group: Analytical and Test Facilities

- Unique Hydraulic Pump Test Facility
- Unique Grazing Angle Infrared Microscope
- High Speed Bearing Tester
- Lubricity Test Equipment
- Extreme Temperature Rheological Property Capability
- In-House Fluid and Component Analysis Capability - e.g., XPS, ICP, SEM, XRD, TEM

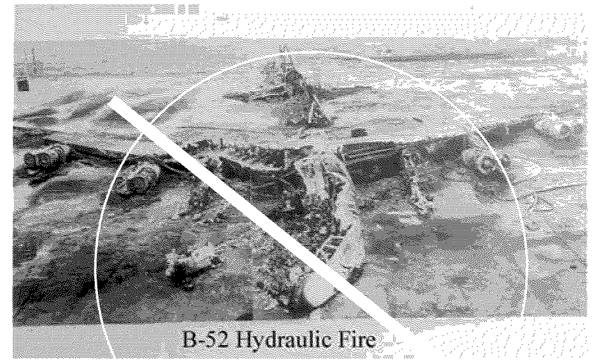


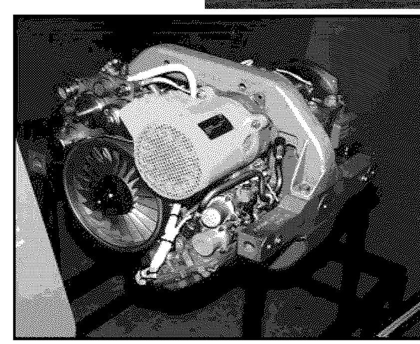
MLBT Fluids and Lubricants Group: Interactions

- **Non-Government/International Organizations and International Standardization Activities**
  - American Society for Testing and Materials (ASTM)
  - Society of Automotive Engineers Aerospace Fluid Power and Control Technologies Committee (SAE A-6)
  - Society of Tribologists and Lubrication Engineers (STLE)
  - International Standards Organization (ISO)
  - North Atlantic Treaty Organization (NATO)
  - Air Standardization and Coordinating Committee (ASCC)
- **Other Government Agencies (Army, Navy, NASA, DLA, FAA)**
- **Industry (Prime contractors, component designers and suppliers, and fluid suppliers)**

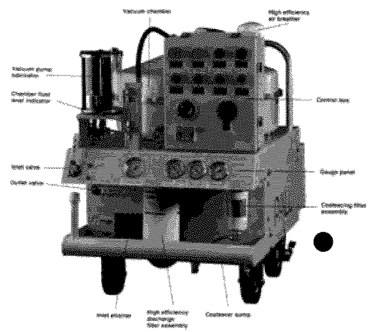
Recent Successes

- Fire resistant hydraulic fluids
  - MIL-PRF-83282 (1980s)
  - MIL-PRF-87257 (1990s)
- Multi-purpose grease
  - MIL-PRF-32014
    - Cruise missile engine
    - C-5/135 Landing gear
    - Seeking other applications





Other Key Areas of Impact



- Other Field Problems
- Accident/Incident Investigations
- Uncommanded Flight Control Inputs
- Cross contamination of hydraulic/lube systems
- Landing gear corrosion
- Other performance anomalies

Value of this Workshop

- Improved communication
- Understand user needs
- Status of newer technology
- Establish new and enhance existing relationships
- Awareness of ML skills/capabilities

Materials & Manufacturing Directorate Summary

- Our Goal is a Full Spectrum, Balanced Program
- Our Technologies are Fundamental to Virtually All Systems
- We are Focused on the Needs of Today's AF and the Technological Superiority of Tomorrow's AF

"Aerospace materials and manufacturing leadership for the Air Force and the nation."


Air Force Research Laboratory (AFRL)
2004 Materials and Manufacturing
Directorate (ML) Roadmap Review
13-15 July 2004
Dayton Convention Center
Dayton, Ohio
Register online at: www.mlroadmap.utcdayton.com

Air Force Hydraulic Fluids – An Overview

Ed Snyder
Air Force Research Laboratory
Materials and Manufacturing Directorate

Air Force Hydraulic Fluids – An Overview

- The Air Force uses three hydraulic fluids
  - Fire resistant hydraulic fluids
    - MIL-PRF-83282, -40 to 400^{o}F
    - MIL-PRF-87257, -65 to 400^{o}F
  - MIL-PRF-5606 –65 to 275^{o}F (non fire resistant)

Air Force Hydraulic Fluids – An Overview

- What does *PRF* in MIL-PRF-83282 or MIL-PRF-87257 stand for?
  - It stands for PERFORMANCE
  - When MIL specs were being discontinued in favor of non-government standards, those that survived had to be for materials considered to be safety of flight materials
  - In order to show that they had been reviewed, revised if necessary and approved as being continued as military specification materials, the designation was changed from showing what they were; e.g., H for hydraulic, L for lubricant, G for grease, they were all changed to PRF.
  - In most cases, no changes in materials occurred, just a change in designation

Air Force Hydraulic Fluids – An Overview

- MIL-PRF-5606 was the standard hydraulic fluid for military and commercial aircraft until the mid ’50s when the large commercial aircraft switched to the fire resistant phosphate ester hydraulic fluids commonly known as Skydrol
- Since these fluids were not compatible with the existing military aircraft hydraulic systems, the military did not change at that time

Air Force Hydraulic Fluids – An Overview

- In the mid-’80s, a need was identified for a more fire resistant hydraulic fluid for the military
  - It had to be
    - Compatible with MIL-PRF-5606
    - Compatible with existing system design
    - Compatible with existing seal technology
  - It had to be a no-retrofit, drop-in replacement for MIL-PRF-5606

Air Force Hydraulic Fluids – An Overview

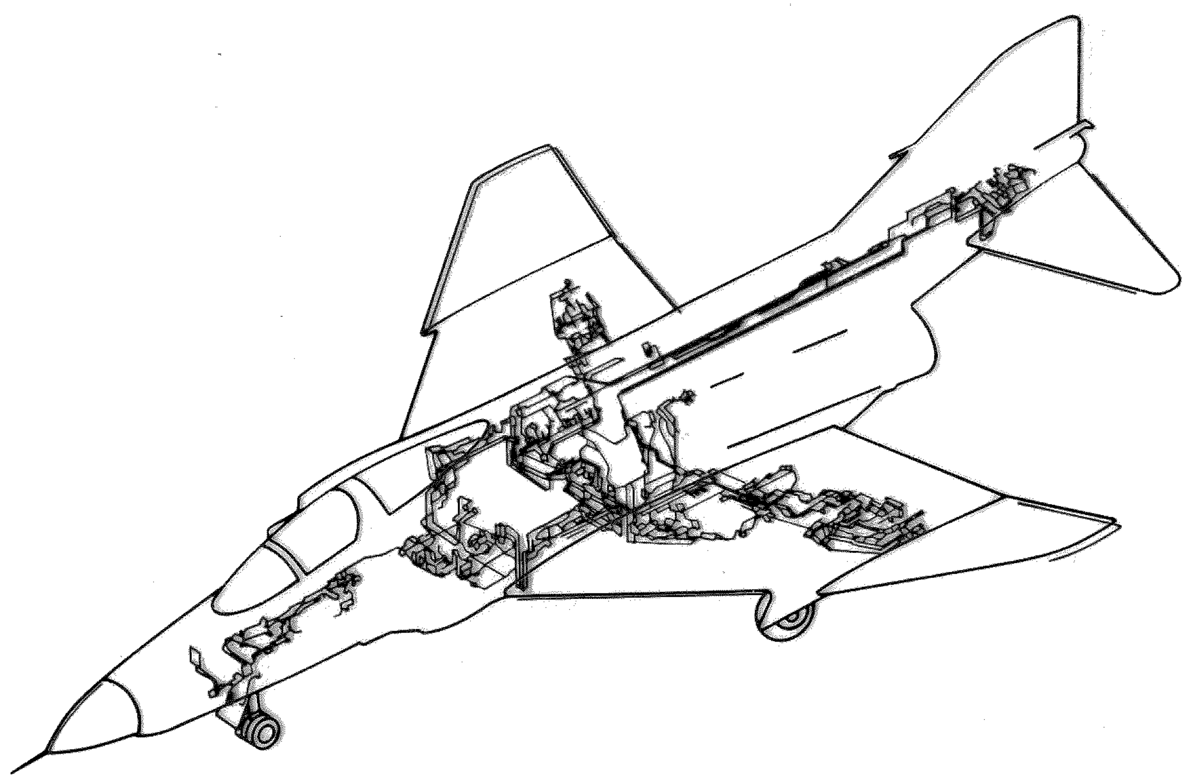
- The major concern was about survivability against enemy gunfire

Air Force Hydraulic Fluids – An Overview

- But there was also considerable concern around the non-combat fire threat
  - High pressure hydraulic systems (3000 to 5000 psi)
  - Widely distributed throughout aircraft
  - Hot surface ignition source
  - Spark ignition sources
  - Propagation of the fire to the fuel system

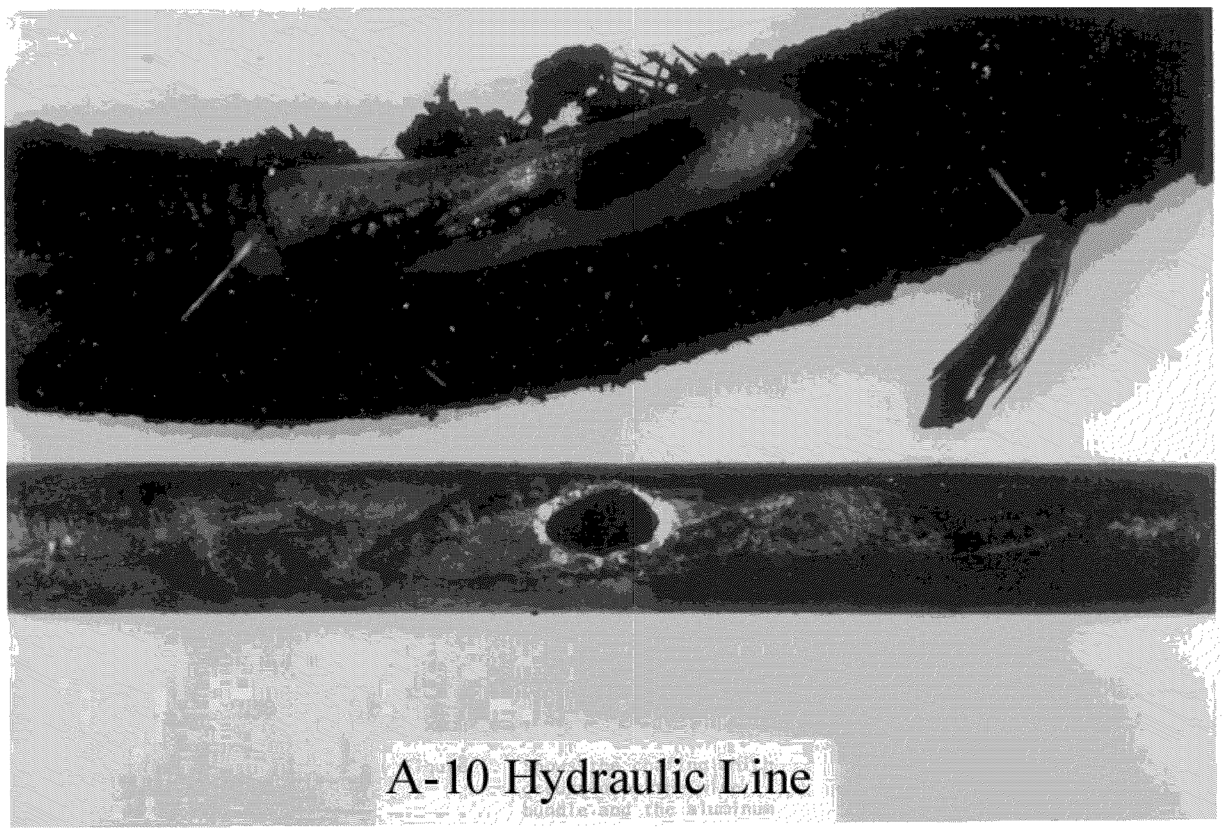
Air Force Hydraulic Fluids – An Overview

- Widely distributed hydraulic systems



Air Force Hydraulic Fluids – An Overview

- Fire Hazards – Electrical Arcing



3 A-10s lost to hydraulic fires in 2 months

44

Air Force Hydraulic Fluids – An Overview

- Fire Hazards – Hot Brakes

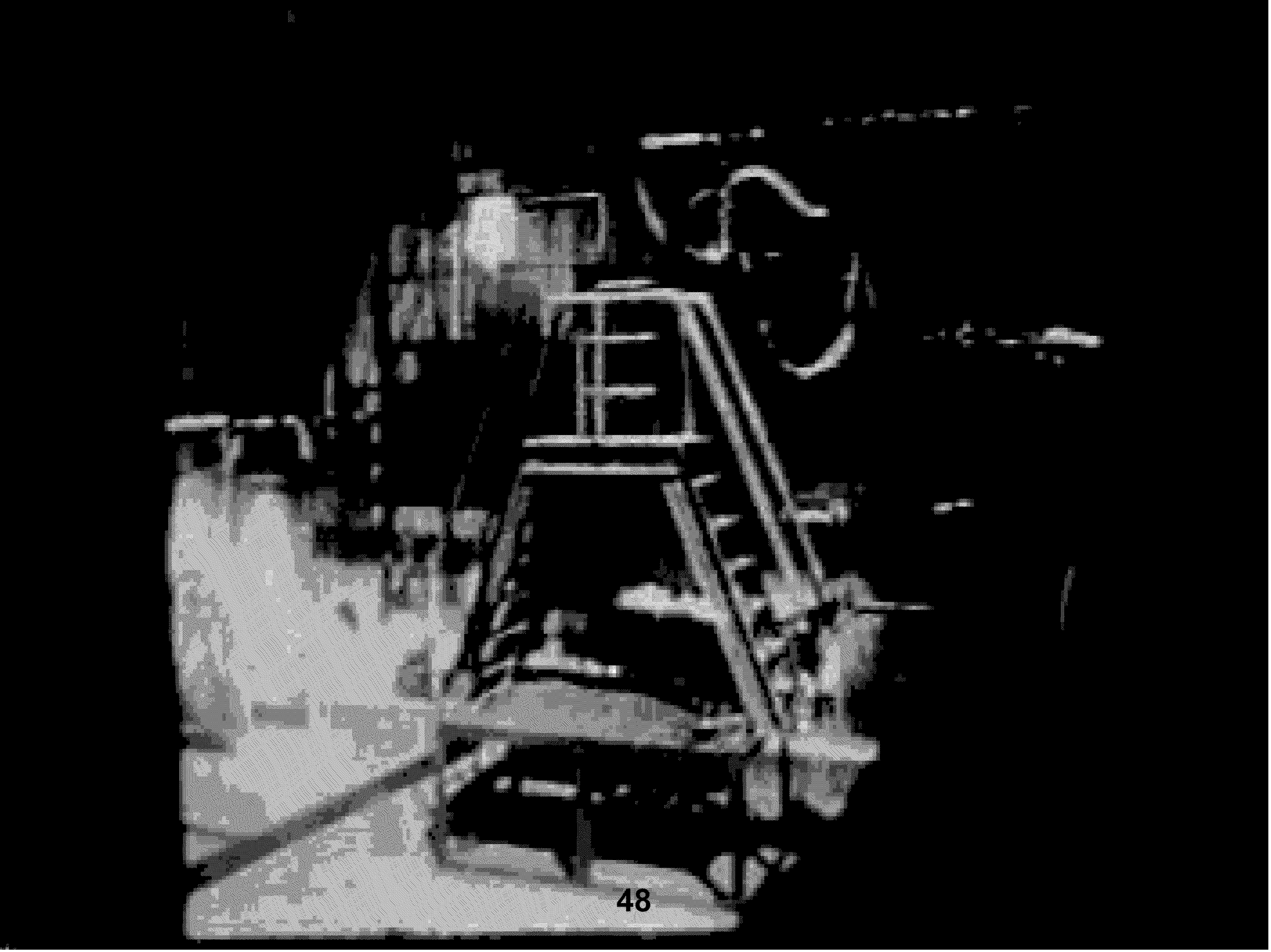
B-52 Hydraulic Fire

Air Force Hydraulic Fluids – An Overview

History

- MIL-H-83282 Specification issued in 1971
  - Navy converted to 83282 in 1976
  - Army aviation converted to 83282 in 1976
  - NASA designed it into the Space Shuttle
  - Air Force converted A-10s in 1980
    - Planned to convert balance of fleet in 1982 if no problems arose
  - In ’80 to ’82 time frame, low temperature aircraft testing demonstrated that poorer low temperature properties could limit deployment in northern tier bases with aircraft on alert
  - A need was developed for a –65°F version of MIL-H-83282
    - MIL-PRF-87257 was developed and validated


47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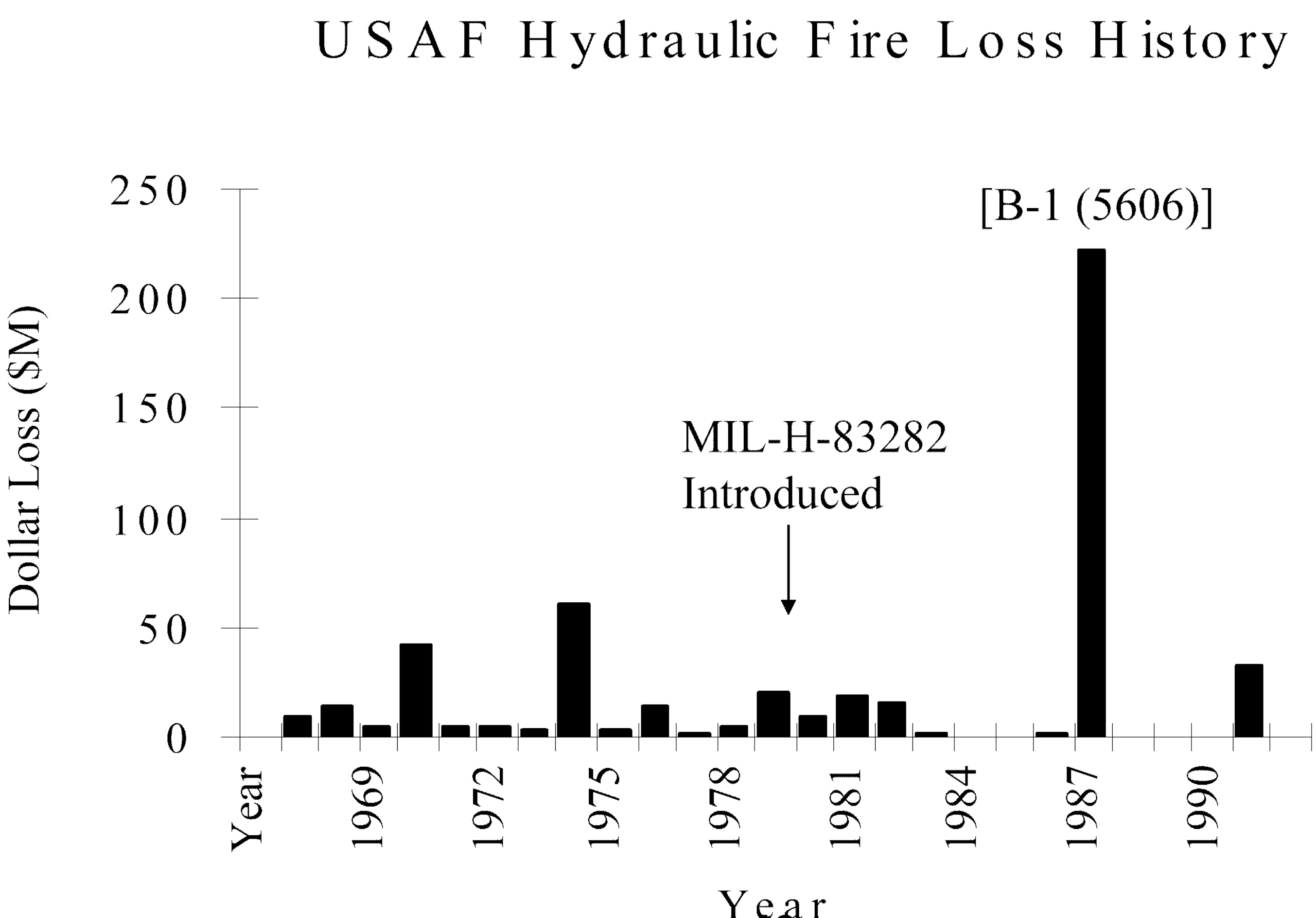
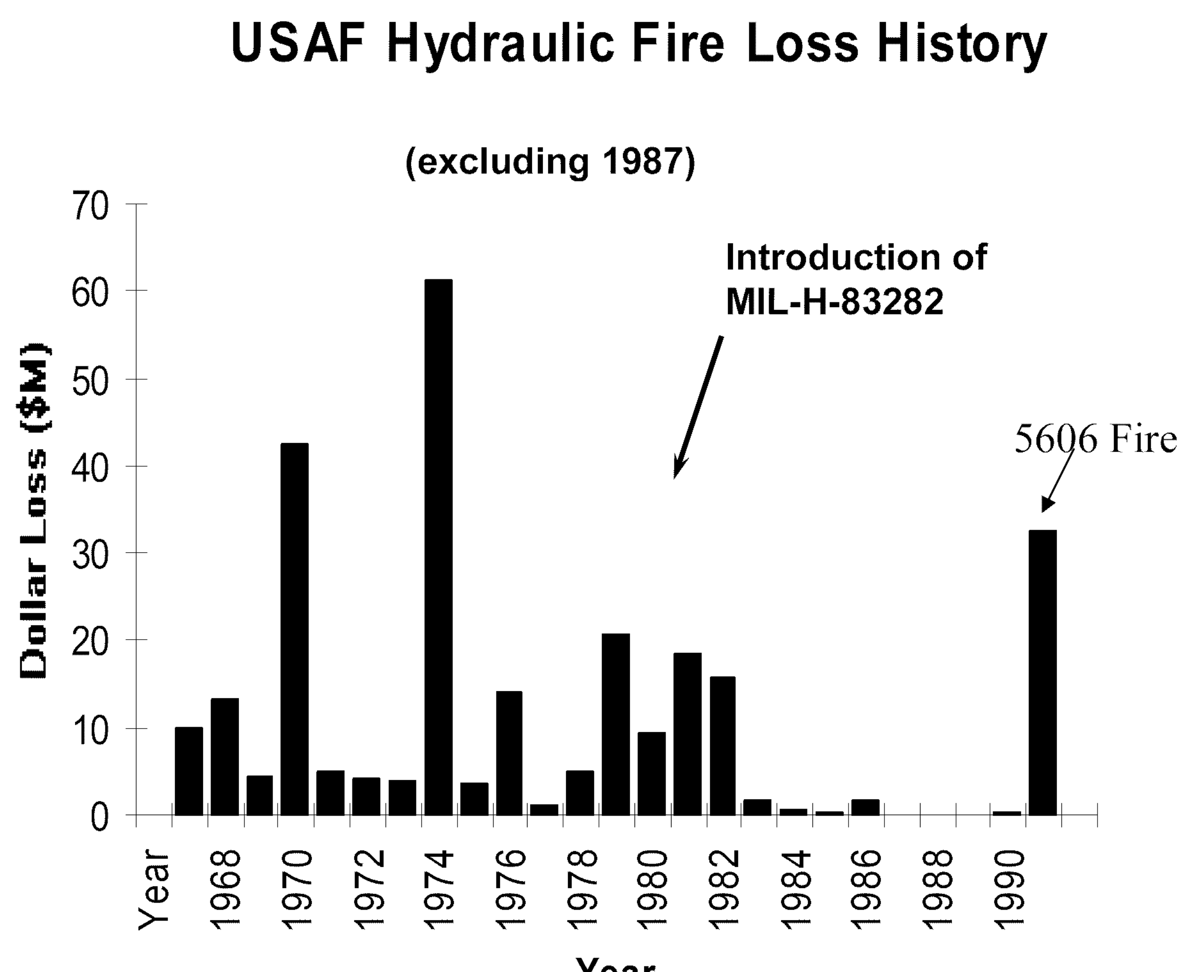
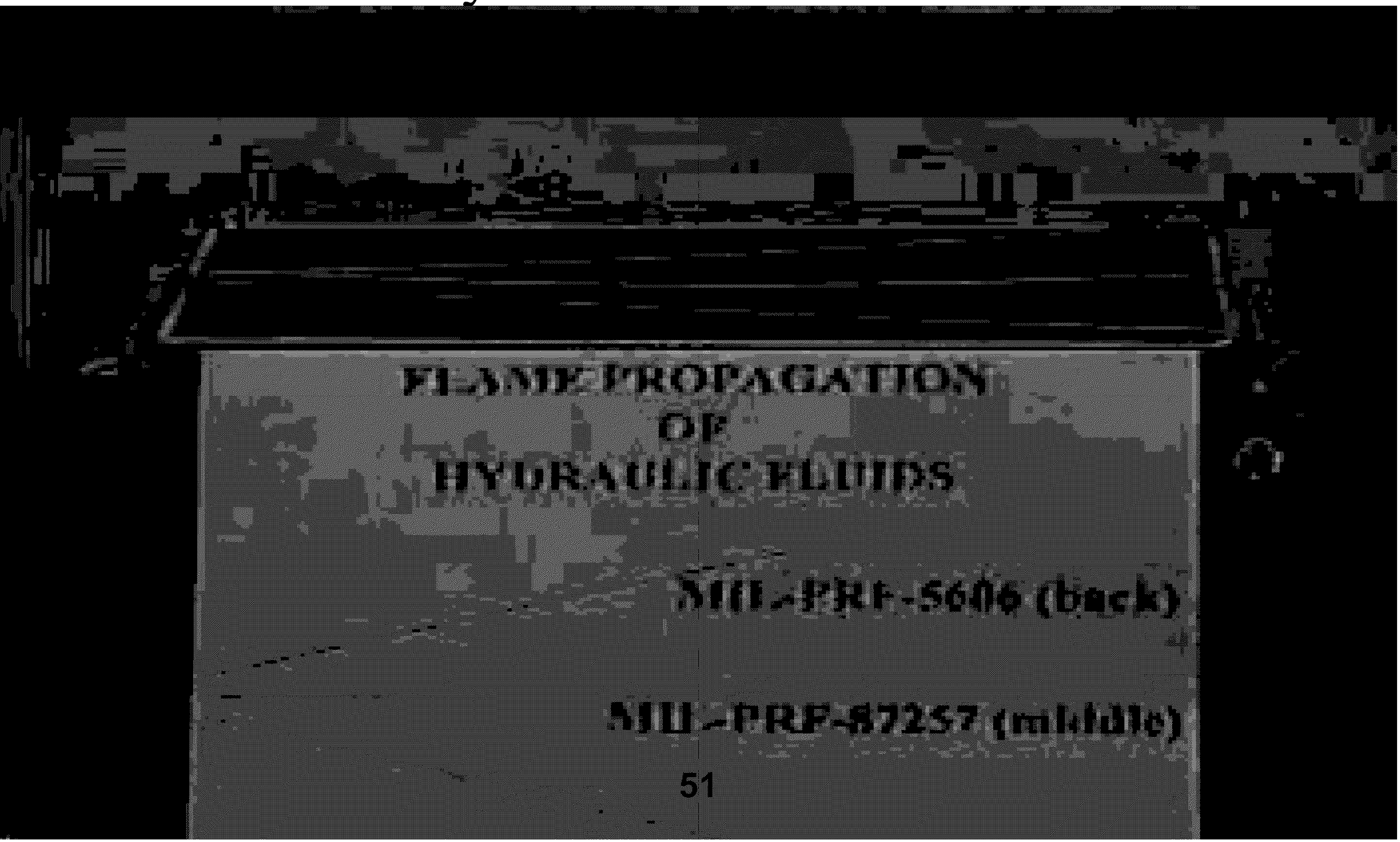
Air Force Hydraulic Fluids – An Overview



Air Force Hydraulic Fluids – An Overview



Air Force Hydraulic Fluids – An Overview



Air Force Hydraulic Fluids – An Overview

Summary

- Nearly all DoD aircraft are using either MIL-PRF-83282 or MIL-PRF-87257 fire resistant hydraulic fluids
  - All aircraft are working fine
    - No operational problems
  - Conversion accomplished by low cost attrition method
- Let's get the last few Air Force aircraft still using MIL-PRF-5606 converted

Air Force Hydraulic Fluids – An Overview

P.S.

One recent event

MIL-PRF-46170 Type II has been cancelled

This has traditionally been used as a storage fluid for many Air Force, Navy and Army Aviation hydraulic system components

It is recommended that the aircraft functional hydraulic fluid (83282, 87257 or 5606) be substituted wherever MIL-PRF-46170 Type II was used

Air Force Lubricant Specifications & Conversions

Lois Gschwender
AFRL/MLBT

June 2004

Specifications (AFRL/MLBT)

- Hydraulic Fluid*
  - MIL-PRF-27601 (hi temp PAO) One company qualifying now - EHA fluid?
  - MIL-PRF-87257 (PAO) (Revised 2004)
  - MIL-PRF-5606 (mineral oil) (Revised 2002)
- *Qualified Products List on these

- Available through ASSIST

  PUBLIC: www.assistdocs.com

  Or http://assist.daps.dla.mil

  (select QuickSearch)

Specifications (AFRL/MLBT)

- Coolant*
  - MIL-PRF-87252 (PAO, dielectric)
- Lubricating Oils*
  - MIL-PRF-6085 (instrument)
  - MIL-PRF-6086 (gear)
  - MIL-PRF-7870 (general purpose)
- Fastener Lubricant
  - MIL-L-87132 (cetyl alcohol)
- Thread compound
  - MIL-PRF-83483 (antiseize, MoS_2)

* <u>Q</u>ualified <u>P</u>roducts <u>L</u>ist on these

Specifications (AFRL/MLBT)

- Grease
  - MIL-PRF-27617* (perfluoropolyalkylether)
  - MIL-PRF-32014* (PAO, Li soap)
  - MIL-PRF-83261 (fluorosilicone, extreme pressure, antiwear)
  - MIL-PRF-83363 (extreme pressure antiwear helicopter transmission)

* Qualified Products List on these

Air Force Hydraulic Fluid Specifications

- MIL-PRF-5606 mineral oil hydraulic fluid – extensive revisions but no change in basic materials or properties – should be “invisible” to aircraft
  - Dated 7 June 2002
  - Remains inactive for new design
  - Current fluids grandfathered
- Lots of re-qualification activity on MIL-PRF-5606 due to base stock supplier changes

Air Force Hydraulic Fluid Specifications

- MIL-PRF-5606 extensive revisions
  - New bulk modulus procedure added as an appendix, part of ASTM D6793
  - Barium limit 10 ppm max, ASTM D5185
  - Up to 3% antiwear additive allowed
  - Low temperature stability changed to FTMS 3458
  - Gravimetric, two filters (not changed)
    - Pre-wash and dry filters before use
    - Dry filters 15 min, 70^{o}C
    - Cover petri dishes

Air Force Hydraulic Fluid Specifications

- MIL-PRF-5606 extensive revisions
  - Water test method changed from ASTM D 1744 to D 6304
  - Alternative pour point ASTM D5949 added
  - Copper strip corrosion changed from testing 3 strips to 2 strips
  - Copper corrosion rinse agent changed from acetone to isooctane

Air Force Hydraulic Fluid Specifications

- MIL-PRF-5606 extensive revisions
  - Interchangeability with other fluids statement
  - Send final formulation only unless ingredients requested
  - Sampling plan simplified
    - Performance oriented
    - Multiple sampling plans (A through D) deleted
  - Notes section 6 more extensive

Air Force Hydraulic Fluid Specifications

- MIL-PRF-87257 extensive revisions but no change in basic materials or properties – should be “invisible” to aircraft
  - New requirements
    - Bulk modulus per ASTM D6793
    - Barium limit 10 ppm max
    - Biodegradability limit of Class I max
  - Format changes
    - Consolidated requirements and tables into comprehensive table I and revised table II
    - Hyperlinks in electronic version goes directly to footnotes in tables

Air Force Hydraulic Fluid Specifications

- MIL-PRF-87257 extensive revisions
  - Changed requirements
    - Lowered flash point to 160°C due to use of automatic equipment that has a lower data bias
    - Added referee particle count method
    - Raised thermal stability test to 200°C and allowed use of test tube to conduct test
    - Changed temperature range in scope from "–54°C to 135°C" to "–54°C to 200°C" to allow use in EHAs

Air Force Hydraulic Fluid Specifications

- MIL-PRF-87257 extensive revisions
  - Changed filter material in gravimetric procedure to polypropylene and added two stacked filter method – better repeatability
  - Changed limit in gravimetric particulate test to 1.0 mg/100 ml fluid max
  - Require only 1 gallon of final formulation – additives on request only
  - Current fluids grandfathered
  - Published April 2004

Air Force Hydraulic Fluid Specifications

- MIL-PRF-5606 & MIL-PRF-87257 extensive spec revisions
- *Acknowledgments to Glenna Dulsky, David Vowell, George Fultz, Angie Campo and Patrick Hellman for technical work and to Sue Breslin, our spec writer*

Air Force Hydraulic Fluid Specifications

- Other specifications will be revised on an urgency basis

Air Force Grease Specification

- MIL-PRF-27617 – perfluoropolyalkylether based greases
  - Type I, –65-300°F
  - Type II, -40 to 400°F
  - Type III, -30 to 400°F
  - Type IV, –100 to 400°F
  - Type V, -100 to 450°F (none currently qualified)

Air Force Grease Specification

- MIL-PRF-27617 is expensive ~$200 to $1000/lb
- Has some wear and corrosion issues
- Should only be used where hydrocarbon based greases are unacceptable
  - LOX & GOX
  - Extreme temperature
- Specification in pretty good shape, not high priority for revision

Air Force Grease Specification

- MIL-PRF-32014 Multipurpose, Nearly Universal Grease
  - Currently working on this document
  - Change Induction Time ASTM D5483 to Bomb Oxidation Stability ASTM D942, 500 hr time and $\leq$ 35 psi limit
  - Fix panel separation test, establishing and writing method
  - May change low temperature torque requirement per ASTM D1478

Air Force Grease Specification

- MIL-PRF-32014 multipurpose grease (con't)
  - Establish two allowable particle contamination levels
    - Cruise missile requirement (30,000 rpm bearings)
    - Less critical particle count version (C-5 landing gears)
  - Establish two NLGI grades, 1 and 2
  - This grease currently in C-5 landing gear flight test
  - Nye Lubricants Rheolube 374A and Air BP Aeroplex 3214 qualified

Air Force Coolant Specification

- MIL-PRF-87252 coolant - minor changes
  - Minor revisions planned
    - Table III fluid properties revised to correct errors

Air Force Specifications

- Qualified Product Lists
  - QPL-5606-31, 6 September 2002
    - 10 qualified suppliers
  - QPL-6085-15, 6 January 2003
    - 5 qualified suppliers
  - QPL-6085-13, 10 February 2003
    - 4 qualified suppliers
  - QPL-32014-2, Amendment 1, 1 August 2003
    - 2 qualified sources
  - QPL-27617-8 (perfluoropolyalkylether grease), 26 May 2004
    - 4 qualified suppliers
    - Types I through IV
  - QPL-87252 and –87257 to be updated
- Products need to be re-qualified every 5 years

Air Force Coolant Specification

- Any issues or concerns with military specifications we control, please contact AFRL/MLBT

Web sites for access to MIL documents via ASSIST:

PUBLIC: www.assistdocs.com

Or http://assist.daps.dla.mil

(select QuickSearch)

Enter partial document info requested.

Full text available for most documents and QPLs.

T.O. 42B2-1-3
Fluids for Hydraulic Equipment

- Revision published 1 Mar 04
  - Owner of aircraft (SPO) approves use of purified fluid
  - Fluid purification process is approved by AFRL/MLBT - Pall Corp and Malabar approved
  - Components no longer required to be stored in preservative fluid – may be stored in operational fluid

Recent Conversions…

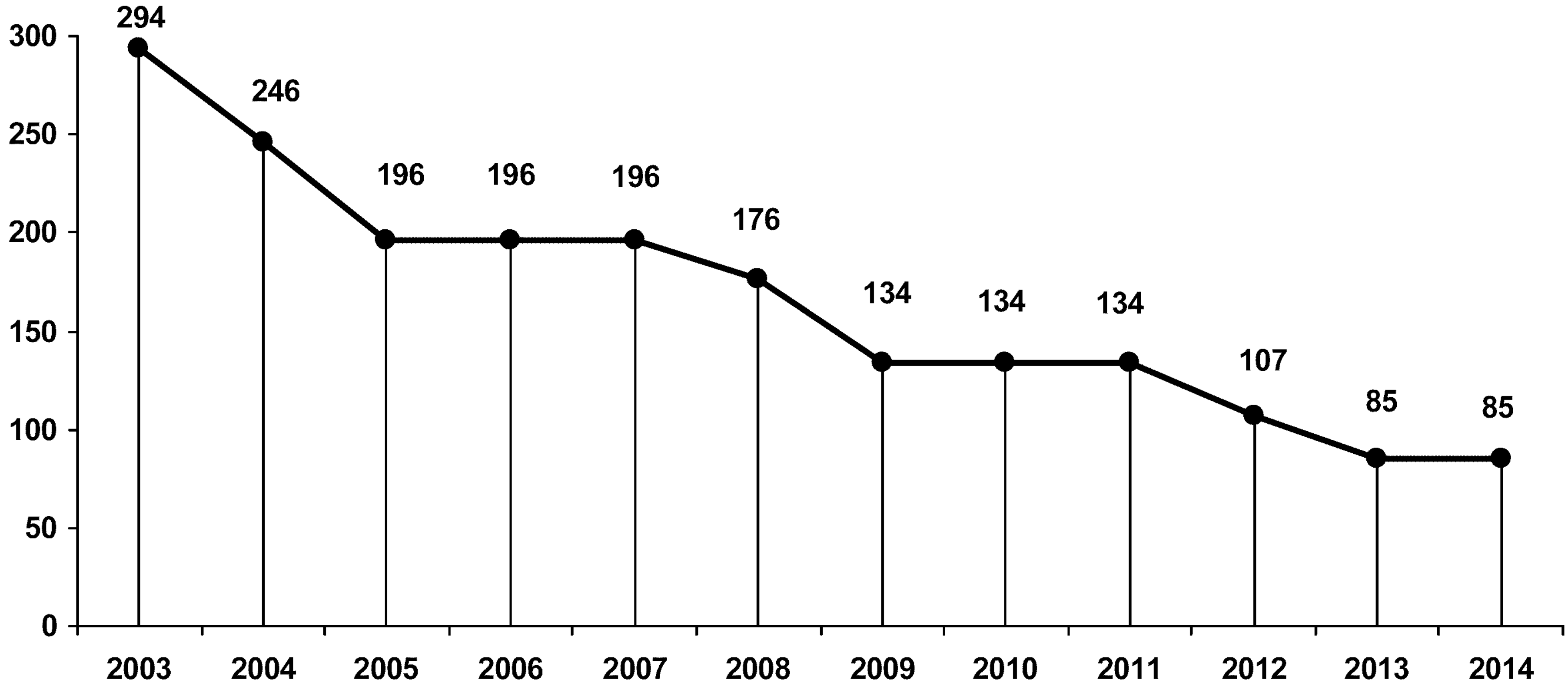
- MIL-PRF-87257 approved for use in B-52 aircraft
  - B-2 and trainers only aircraft using flammable MIL-PRF-5606
- MIL-PRF-32014 replacing MIL-PRF-81322 as grease for main landing gear in C-5 and KC/C–135 aircraft

EADS ESG

Military Aerospace Fluids and Lubricants Workshop

Wright Patterson AFB
Dayton, Ohio
14 – 17. June 2004

GAF TORNADO FLEET DEVELOPMENT



FBW 38“F“
and NaW 2
out-of-service

Installation
EF 2000
at FBW 31“B“
78

Installation
EF 2000
at FBW 33


German Air Force
Status of Conversion to
MIL-PRF-83282 / MIL-PRF-87257

Review: OUTLOOK / TIMESCALE 2002

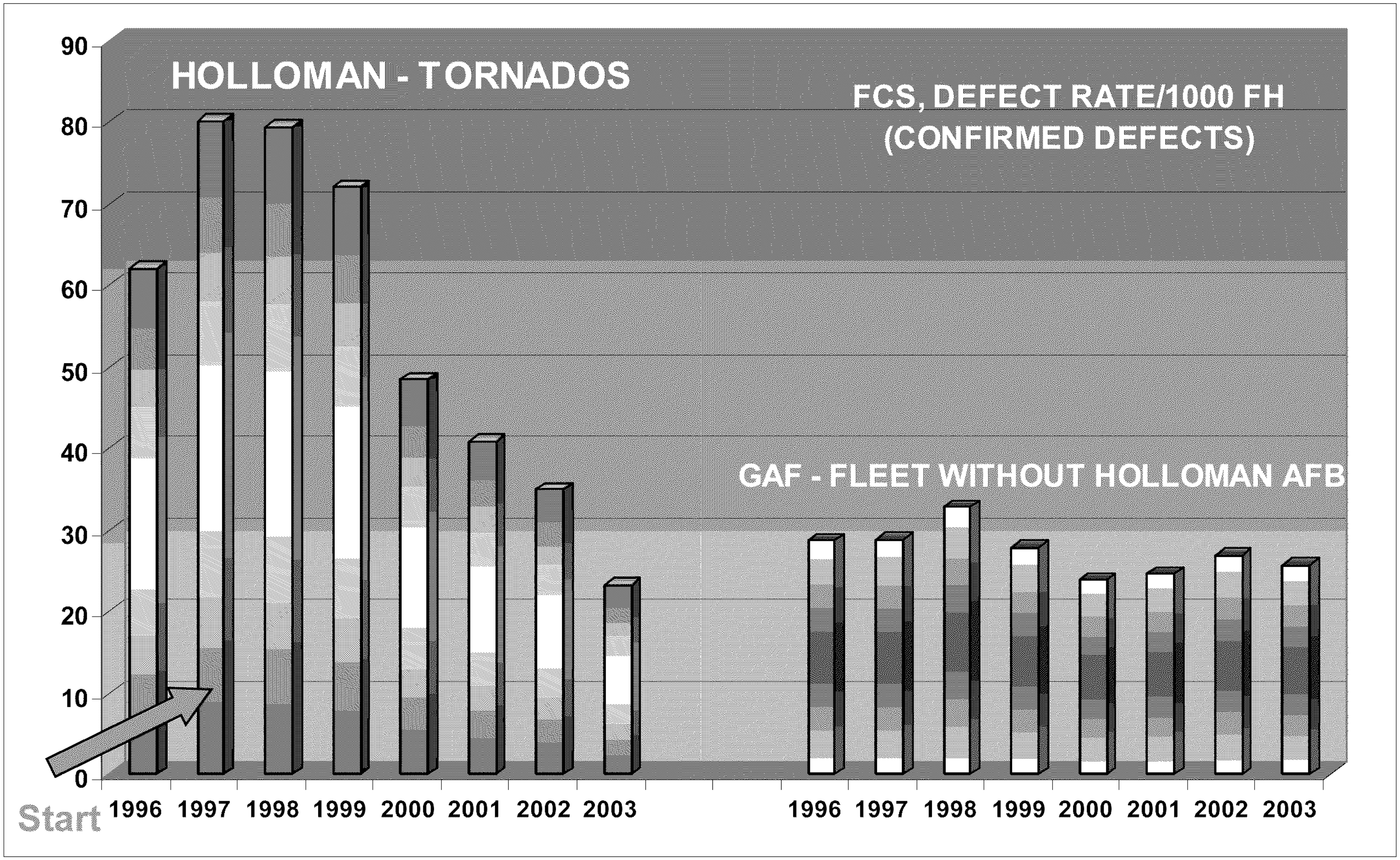
1. Conduct Cold Soak Flight Trials / 3. Q. 2002
2. Qualification of MIL-PRF-83282 for WS TORNADO / End 2002
3. Fleetwide Conversion by Attrition / Complete End 2003
4. Proposal to Partner Nations UK, IT & Saudi

MIL-PRF-83282

Status Holloman AFB, June 2004:

- 35 A/C´s converted yet
- > 32.000 F/H´s operated with MIL-PRF- 83282
- No further problems after solving initial leakages

Improvement of the Defect Rate



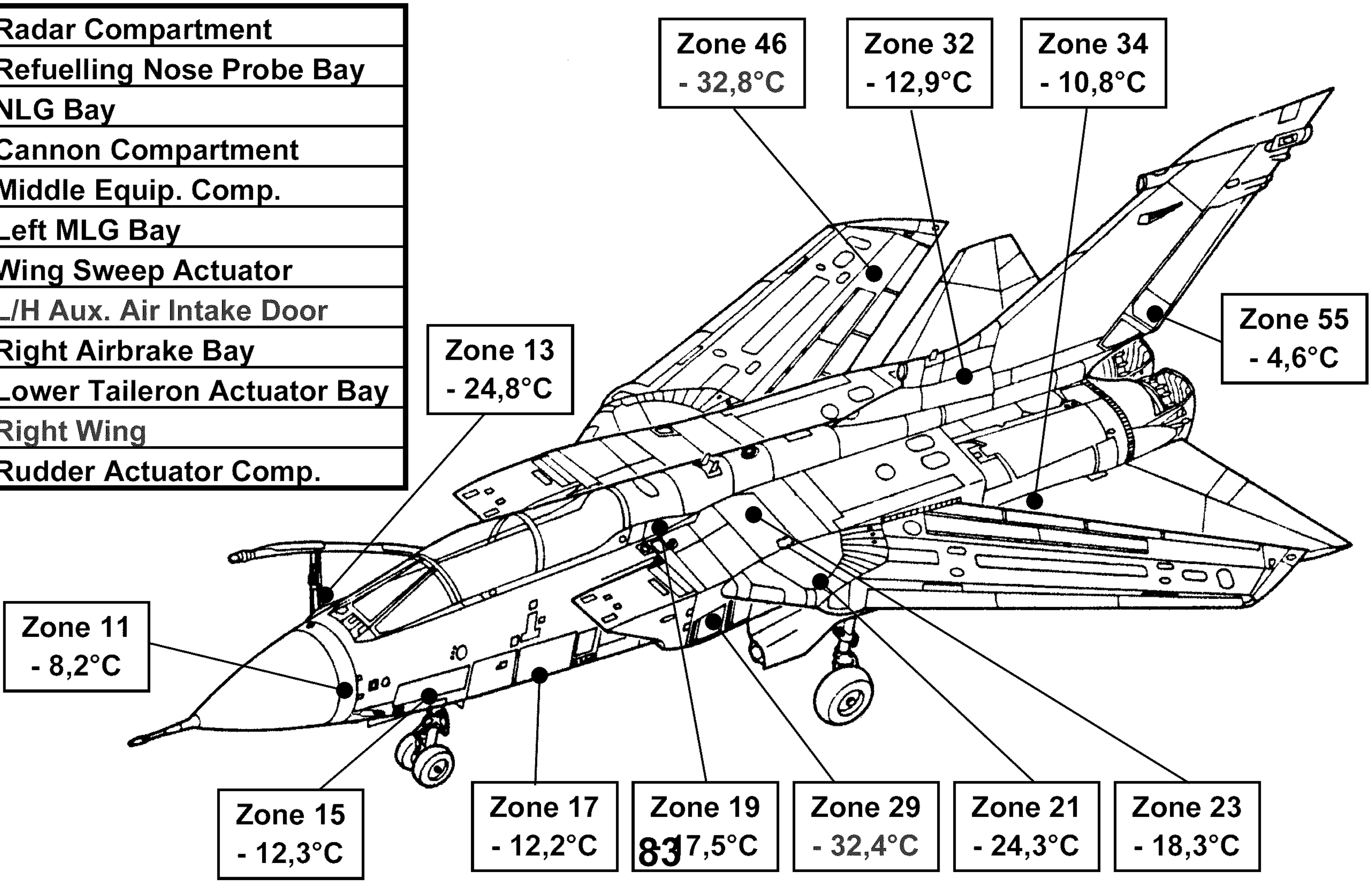
Better Defect-Behaviour after re-oiling to MIL-PRF-83282

Cold Soak Flight Test

EADS — ESG

Location of Temperature Gauges and Lowest Recorded Bay Temperatures (°C)

11	Radar Compartment
13	Refuelling Nose Probe Bay
15	NLG Bay
17	Cannon Compartment
19	Middle Equip. Comp.
21	Left MLG Bay
23	Wing Sweep Actuator
29	L/H Aux. Air Intake Door
32	Right Airbrake Bay
34	Lower Taileron Actuator Bay
46	Right Wing
55	Rudder Actuator Comp.



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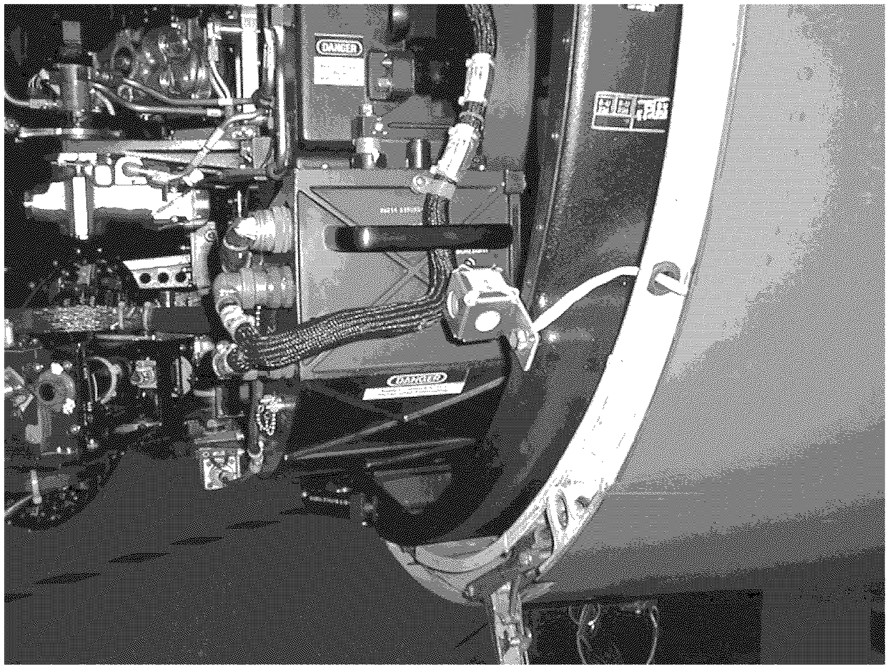
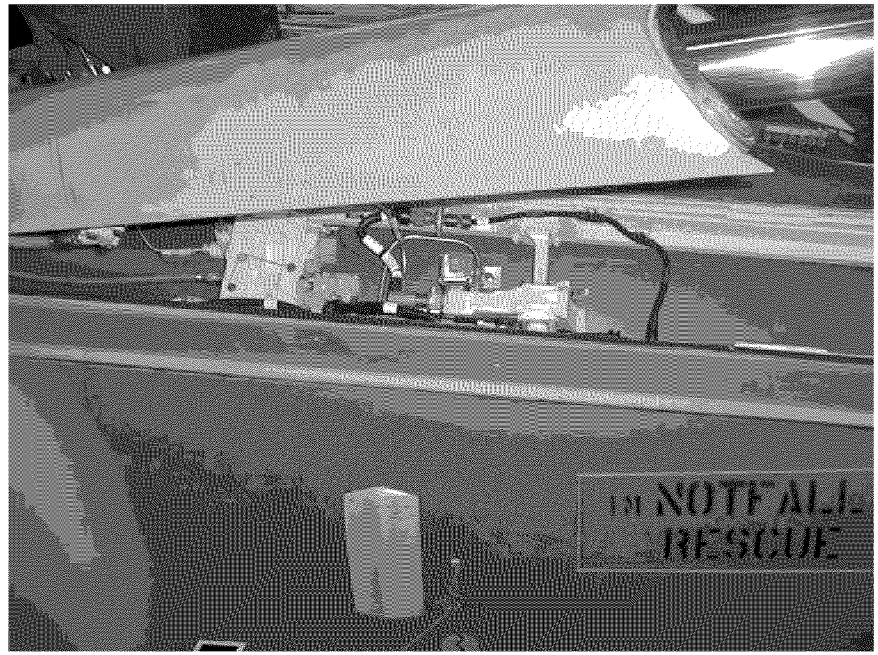


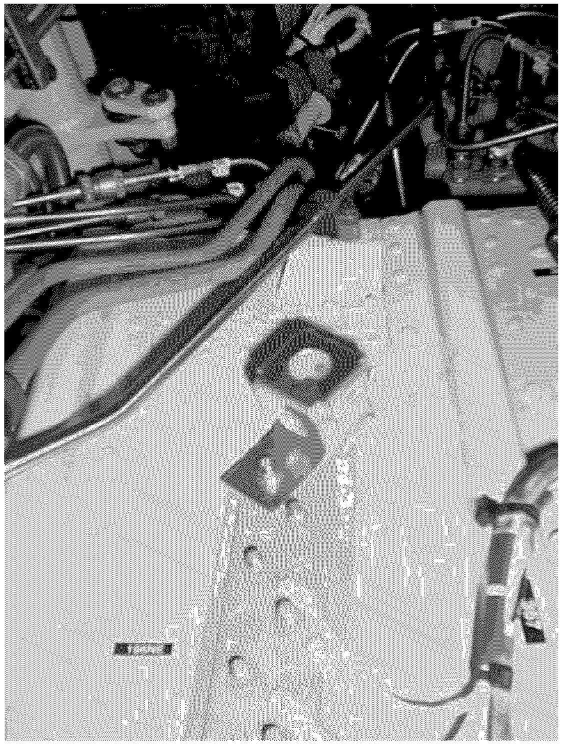


Zone 11 – Radar Compartment

- 8,2 °C / 17,2 °F

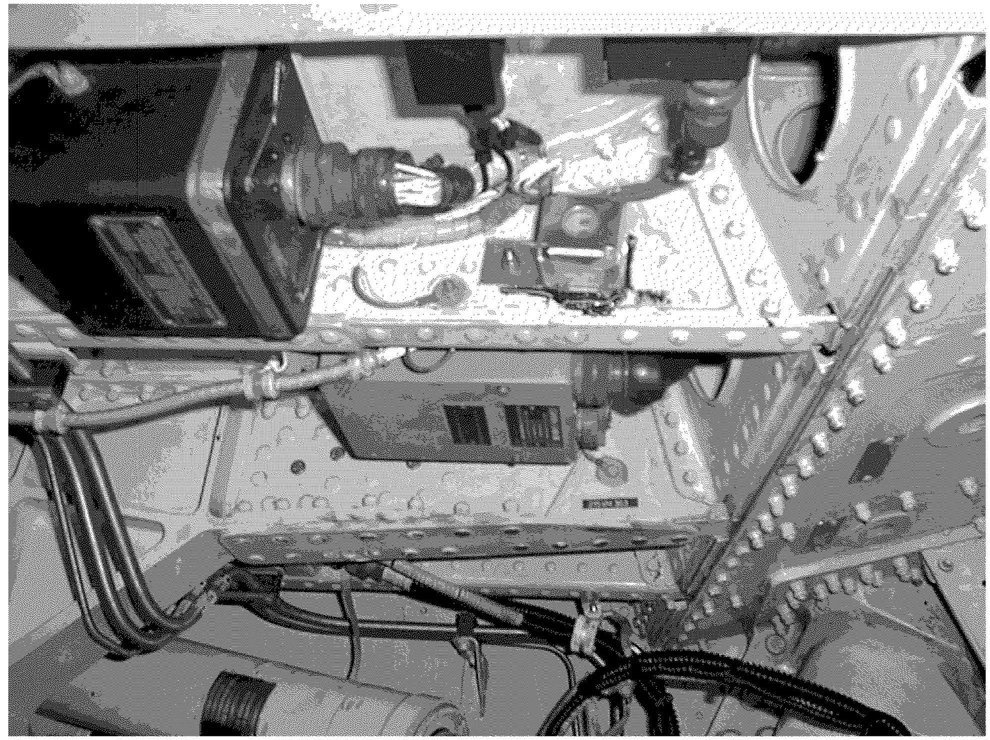
Zone 13 – Refuelling Probe Bay

- 24,8 °C / - 12,6 °F



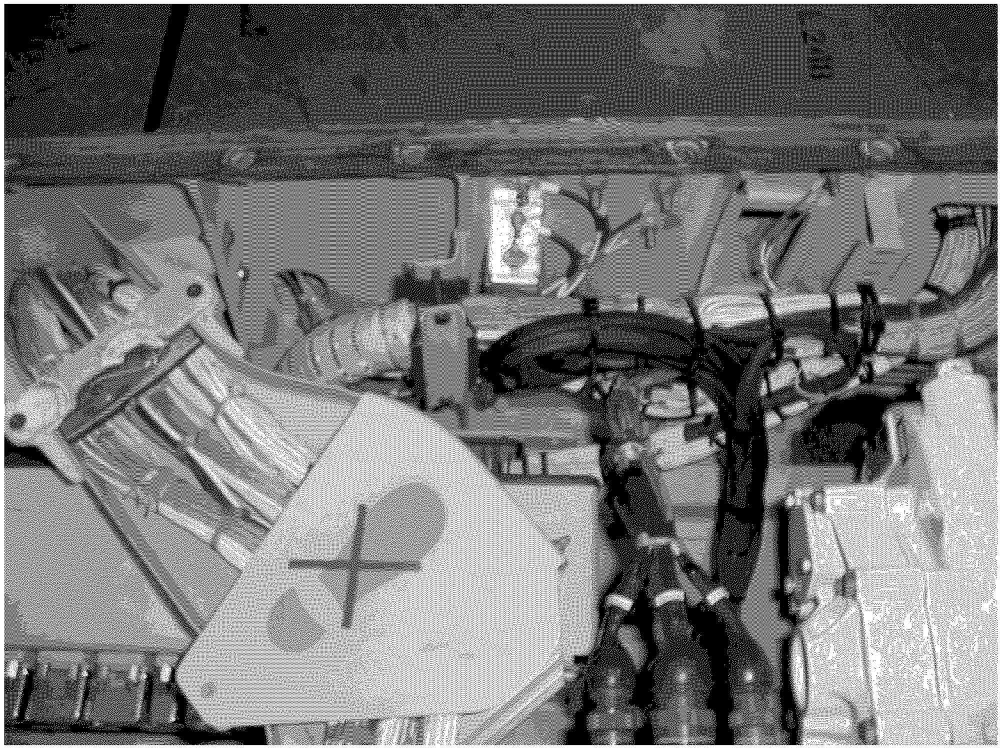
Zone 19 – Center Fuselage

- 17,5 °C / 0,5 °F



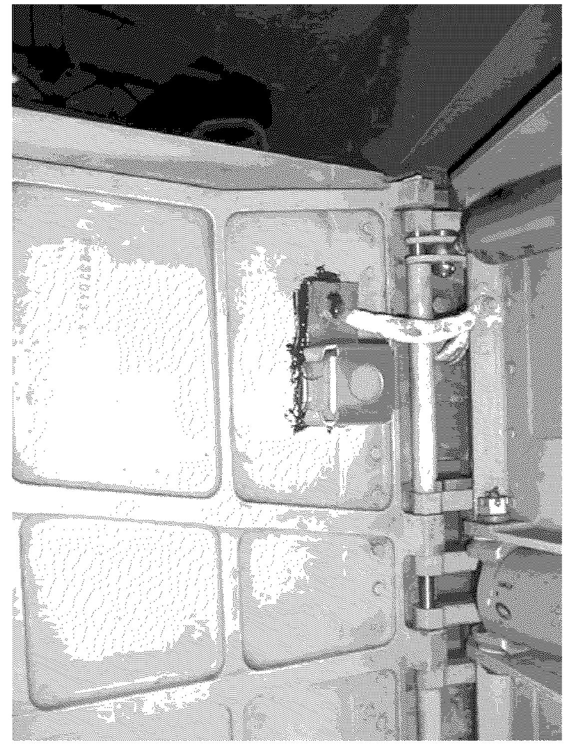
Zone 21 – Main Landing Gear Bay

- 24,3 °C / - 11,7 °F



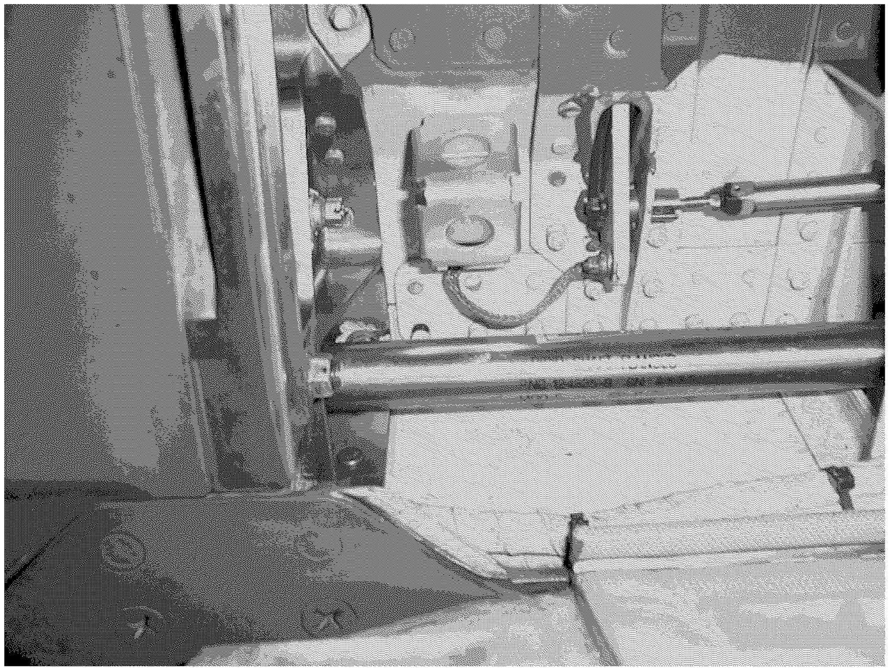
Zone 23 – Wing Sweep Actuator

- 18,3 °C / - 1 °F



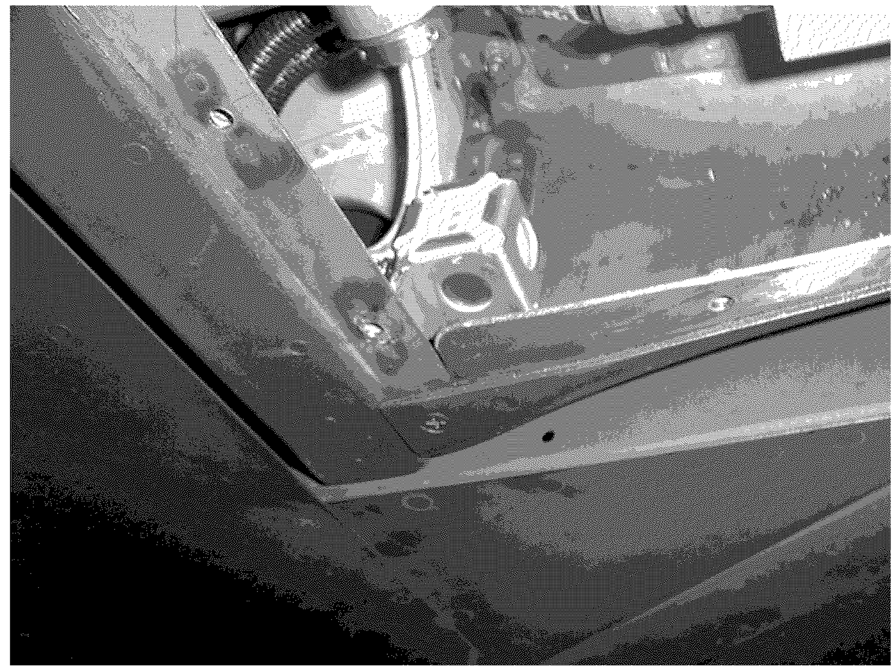
Zone 29 – Auxillary Air Intake

- 32,4 °C / - 26,3 °F



Zone 46 – Outer Wing

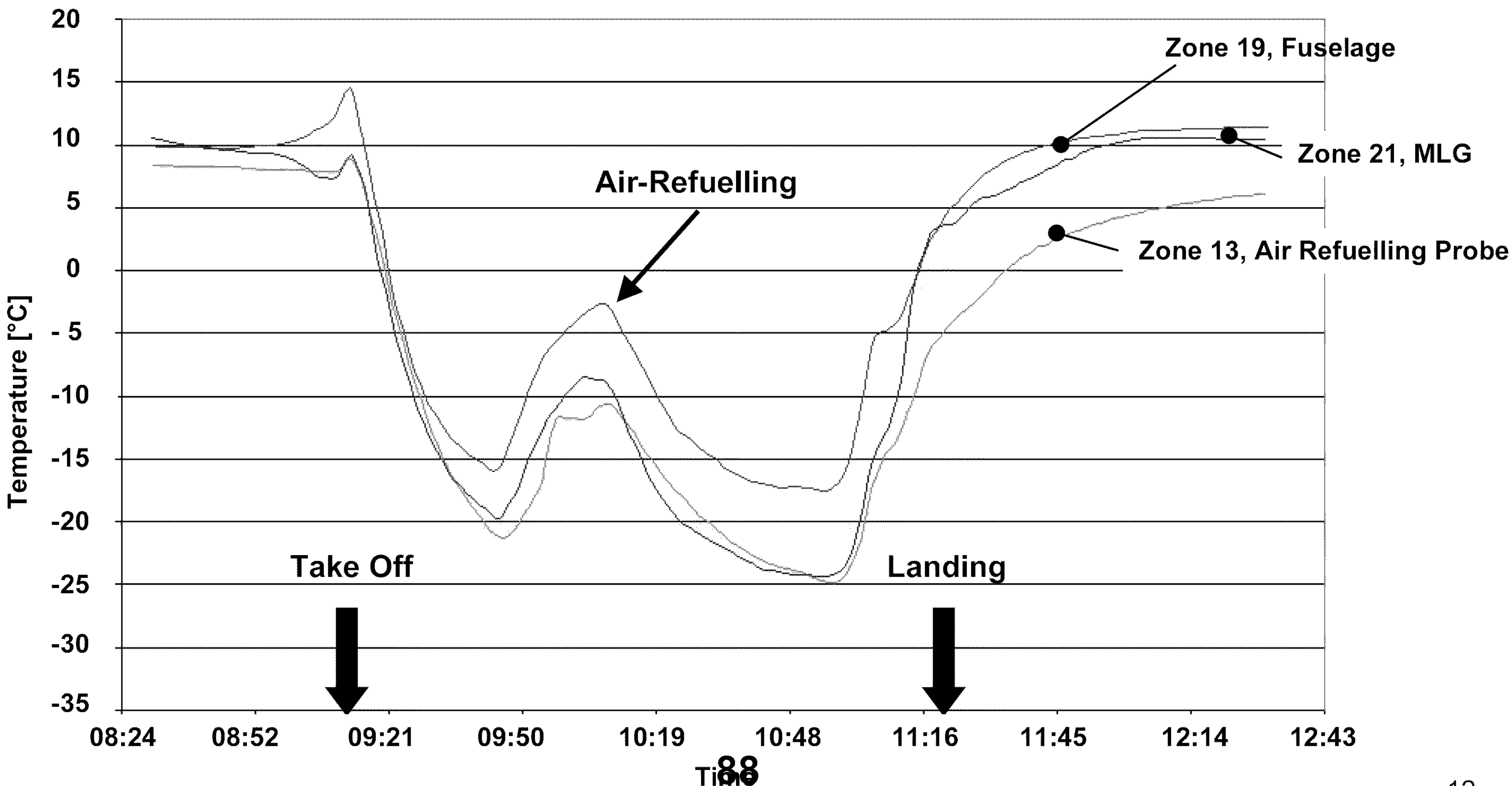
- 32,8 °C / - 27 °F



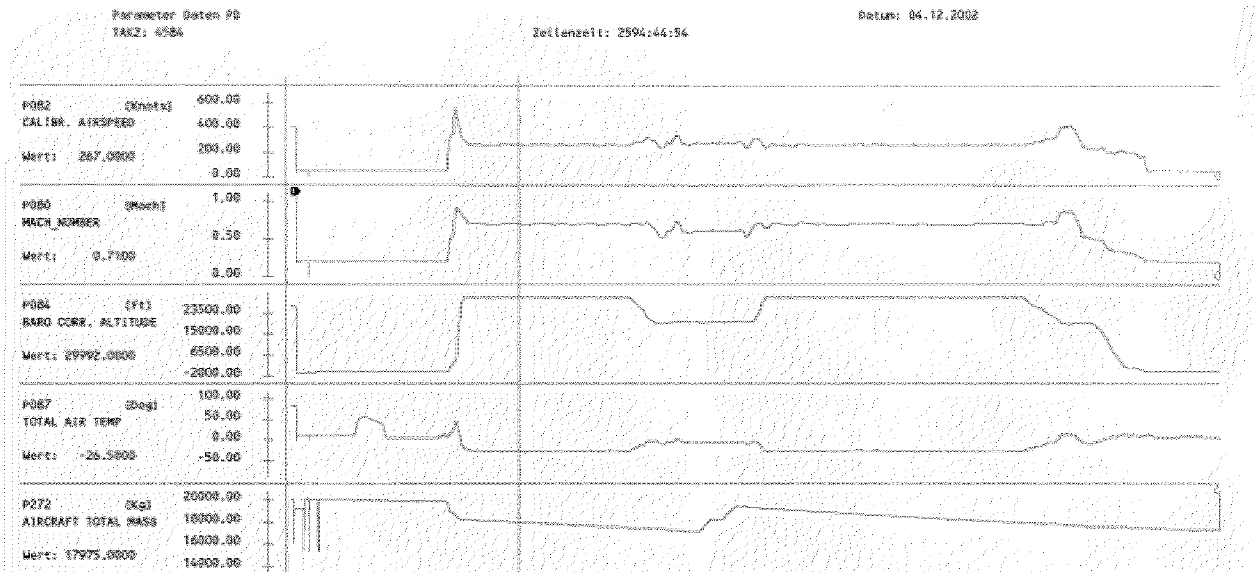
Zone 55 – Rudder Compartment

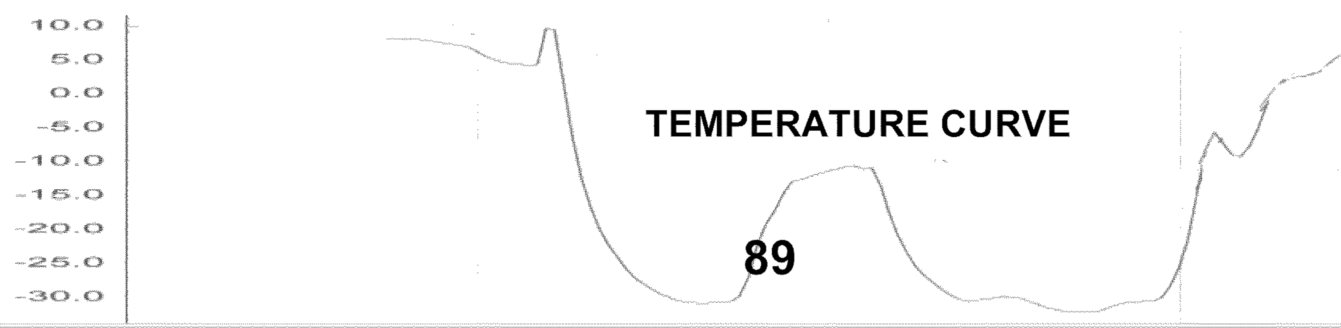
- 4,6 °C / 23,7 °F

Temperature Measurements Tornado



Temperatur Aux. Air Intake



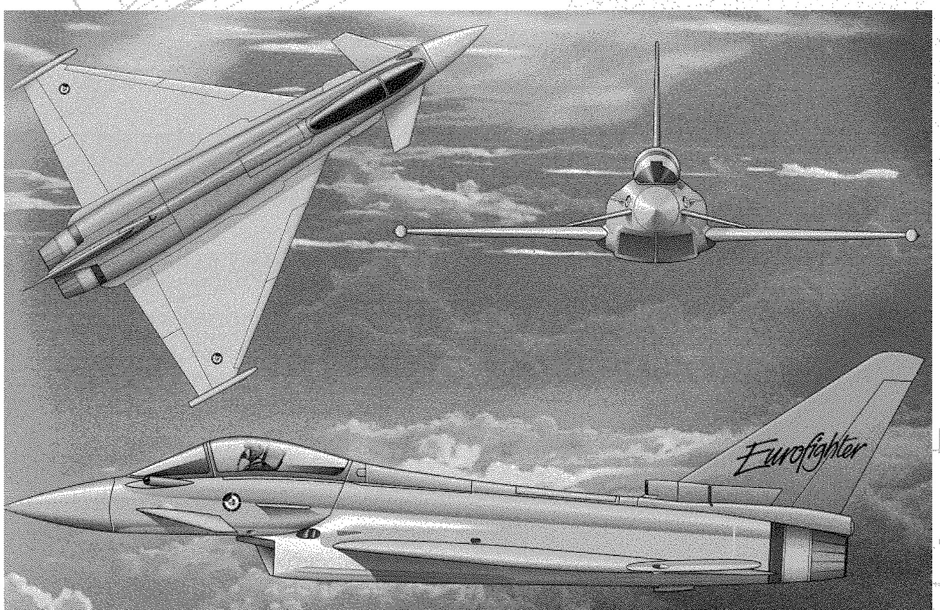


Further Proceeding

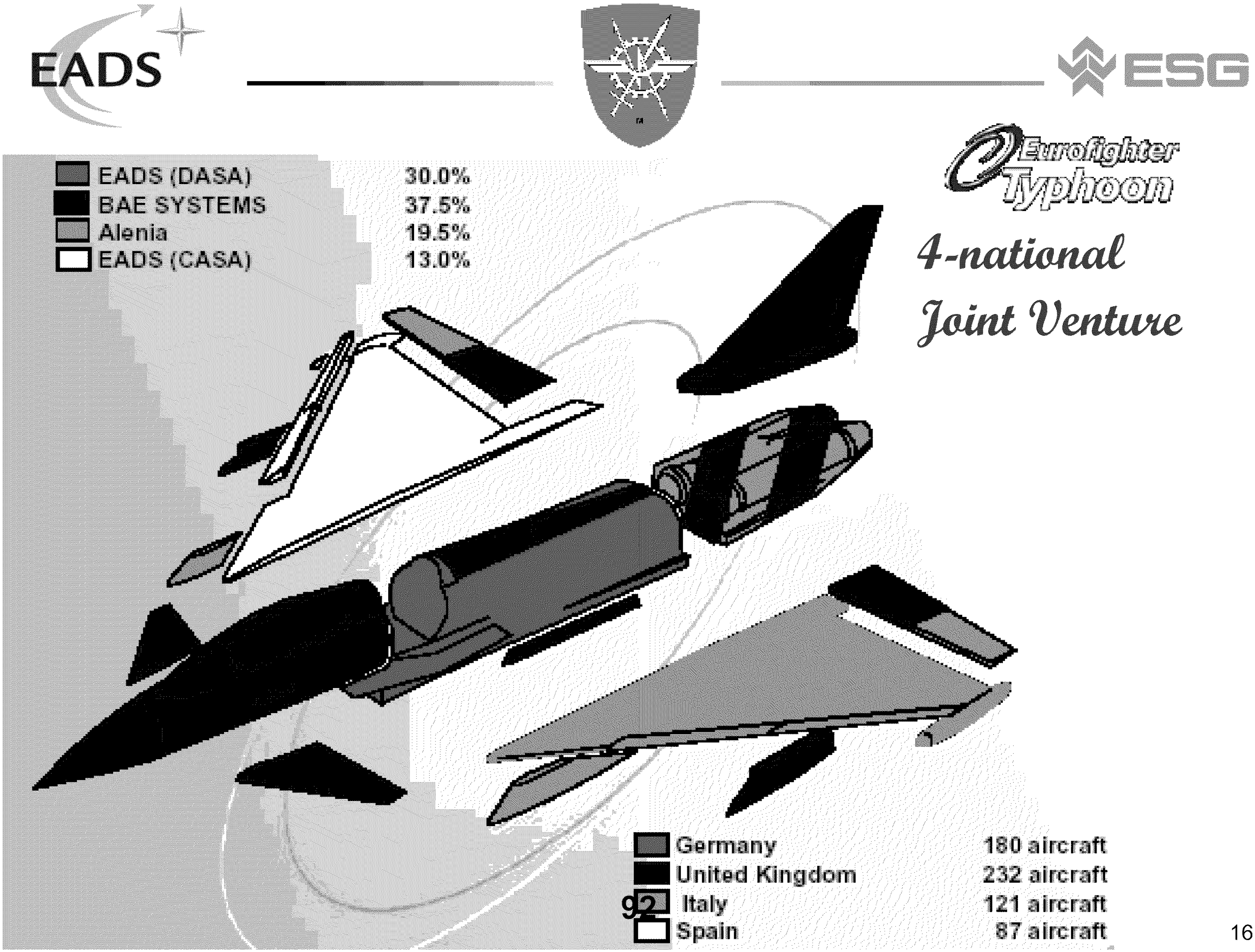
- Selection of suitable type of oil for WS Tornado
  - i.e. MIL-PRF-83282 or MIL-PRF-87257

Eurofighter Typhoon

Data Summary



Performance:	
Maximum Level Speed	Mach 2,0
G Attained to Date	+9 / -3
General Dimensions:	
Wing Span	10,95 m
Length	15,96 m
Height	5,28 m
Masses:	
Operational Mass Empty	11 t
Max. Take-off Mass	24 t
Engines: 2x Eurojet EJ 200	
Thrust Dry	60 kN
Thrust Reheated	90 kN



Eurofighter Typhoon
4-national
Joint Venture
EADS (DASA) 30.0%
BAE SYSTEMS 37.5%
Alenia 19.5%
EADS (CASA) 13.0%
Germany 180 aircraft
United Kingdom 232 aircraft
Italy 121 aircraft
Spain 87 aircraft

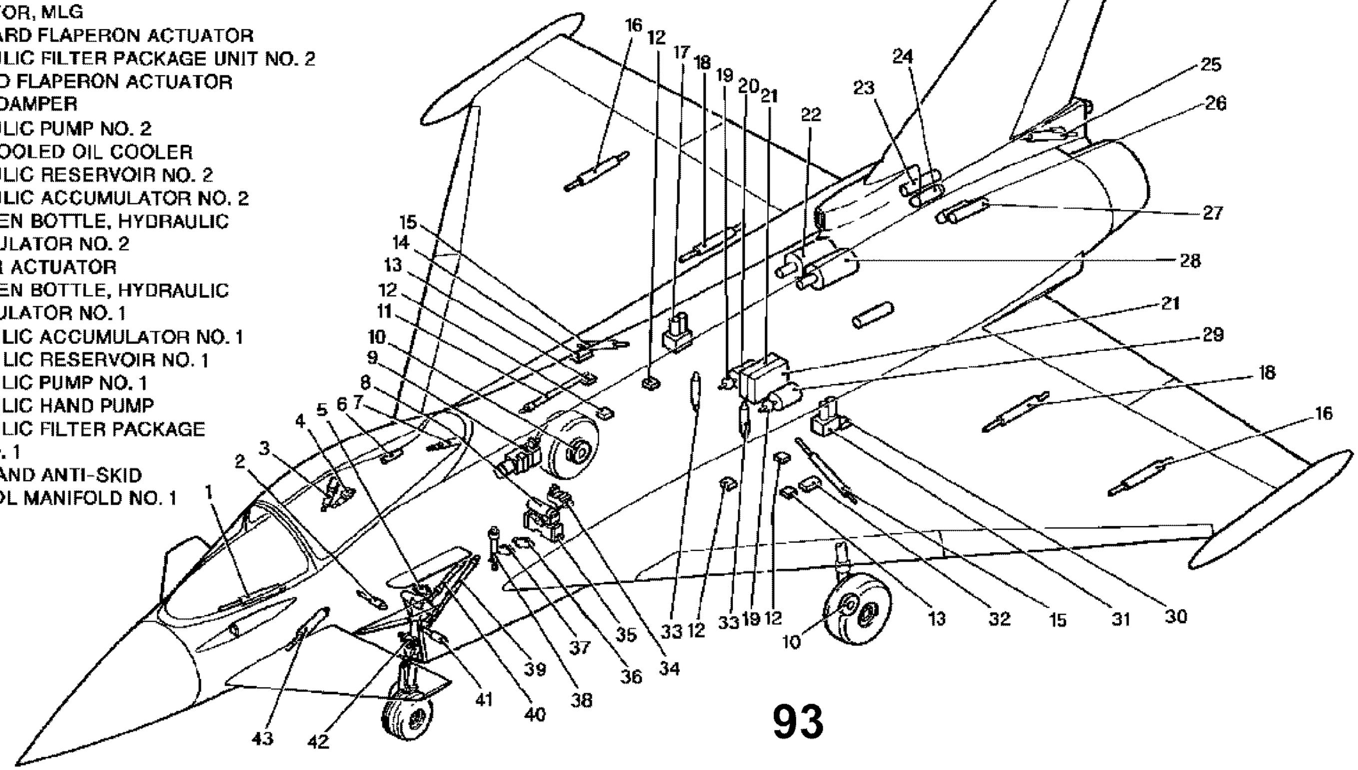
92

EADS — ESG

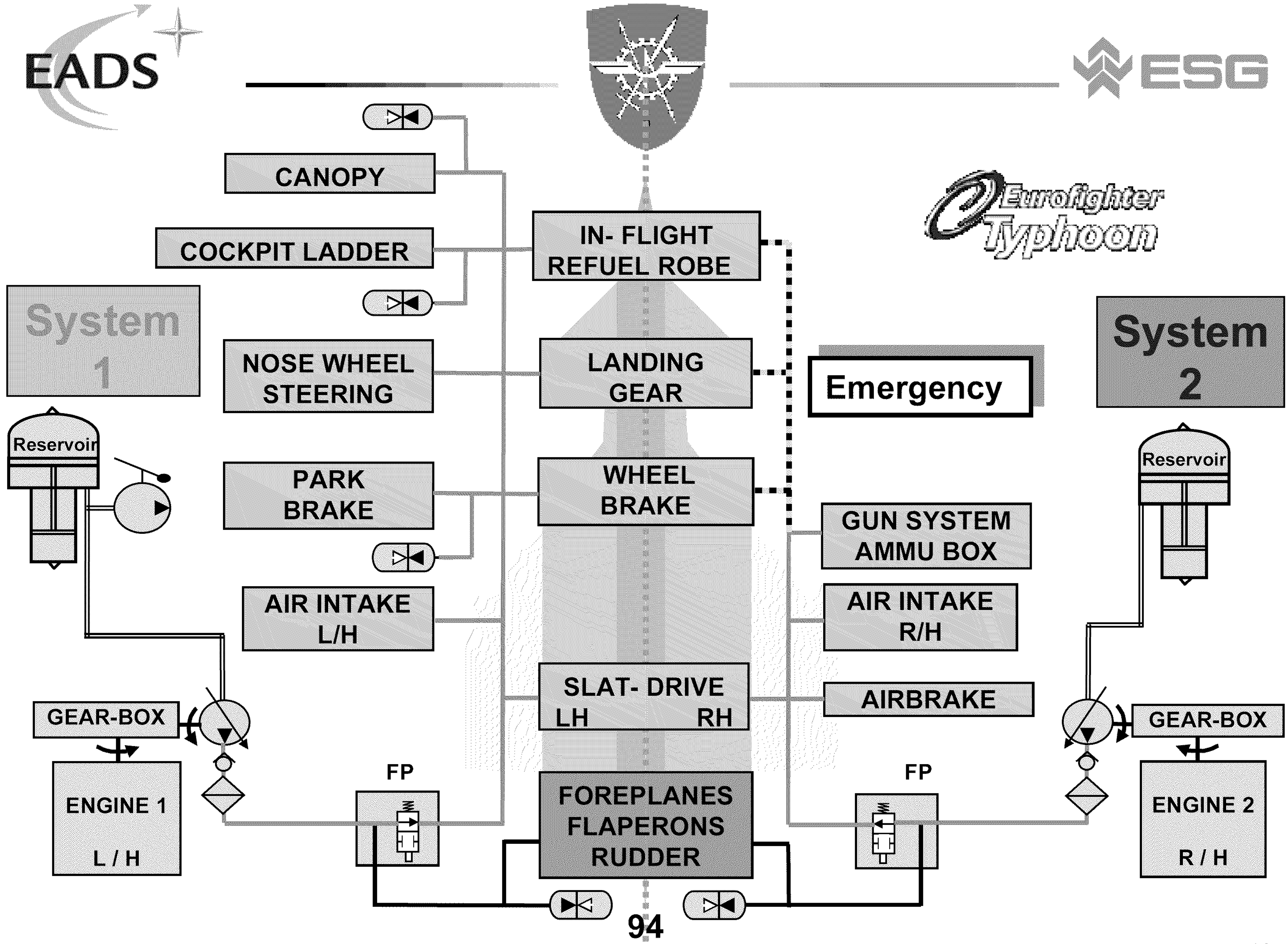
Eurofighter Typhoon

Hydraulics/FCS Configuration

1 FOREPLANE ACTUATOR, RH
2 AIR-INTAKE ACTUATOR, RH
3 IN-FLIGHT REFUELING PROBE ACTUATOR
4 IN-FLIGHT REFUELING PROBE DOOR ACTUATOR
5 DOOR LOCK, FRONT, NLG
6 CANOPY ACCUMULATOR
7 CANOPY ACTUATOR
8 PARKING BRAKE MODULE
9 HYDRAULIC DRIVE, LINKLESS AMMUNITION BOX
10 WHEEL BRAKE
11 AIRBRAKE ACTUATOR
12 DOOR LOCK, MLG
13 UPLOCK, MLG
14 BRAKE AND ANTI-SKID CONTROL MANIFOLD NO. 2
15 ACTUATOR, MLG
16 OUTBOARD FLAPERON ACTUATOR
17 HYDRAULIC FILTER PACKAGE UNIT NO. 2
18 INBOARD FLAPERON ACTUATOR
19 RIPPLE DAMPER
20 HYDRAULIC PUMP NO. 2
21 FUEL-COOLED OIL COOLER
22 HYDRAULIC RESERVOIR NO. 2
23 HYDRAULIC ACCUMULATOR NO. 2
24 NITROGEN BOTTLE, HYDRAULIC ACCUMULATOR NO. 2
25 RUDDER ACTUATOR
26 NITROGEN BOTTLE, HYDRAULIC ACCUMULATOR NO. 1
27 HYDRAULIC ACCUMULATOR NO. 1
28 HYDRAULIC RESERVOIR NO. 1
29 HYDRAULIC PUMP NO. 1
30 HYDRAULIC HAND PUMP
31 HYDRAULIC FILTER PACKAGE UNIT NO. 1
32 BRAKE AND ANTI-SKID CONTROL MANIFOLD NO. 1
33 ACTUATOR, MAIN LANDING GEAR DOOR
34 LANDING GEAR VALVE MANIFOLD
35 SLAT POWER DRIVE UNIT INCL. HYDRAULIC MOTORS
36 DOOR LOCK, REAR, NLG
37 UPLOCK, NLG
38 ACTUATOR, NLG DOOR
39 TELESCOPIC LOCKING STAY, NLG
40 ACTUATOR, NLG
41 AIR-INTAKE ACTUATOR, LH
42 NOSE WHEEL STEERING SYSTEM
43 FOREPLANE ACTUATOR, LH



93



EADS
ESG
Eurofighter Typhoon
CANOPY
COCKPIT LADDER
System 1
NOSE WHEEL STEERING
Reservoir
PARK BRAKE
AIR INTAKE L/H
GEAR-BOX
ENGINE 1 L / H
FP
IN- FLIGHT REFUEL ROBE
LANDING GEAR
WHEEL BRAKE
SLAT- DRIVE LH RH
FOREPLANES FLAPERONS RUDDER
94
Emergency
GUN SYSTEM AMMU BOX
AIR INTAKE R/H
AIRBRAKE
FP
System 2
Reservoir
GEAR-BOX
ENGINE 2 R / H

Hydraulic Technical Data

Hydraulic Fluid	Mil-PRF-5606	
	(CR099 Introduction of Mil-PRF-87257 and Mil-PRF-83282)	
Temperature Range	-31°C to 135°C	operational
	-54°C	non operational
Filtration Standard	NAS 1638 Class 7 to 9	
	HP 15 μm abs., LP 5 μm abs.	
Seals Grooves	to Mil-G-5514	
	Materials Mil-P-83461, Mil-R-8791	
Service Life	6000 FH	
Maintenance Concept	On Condition	

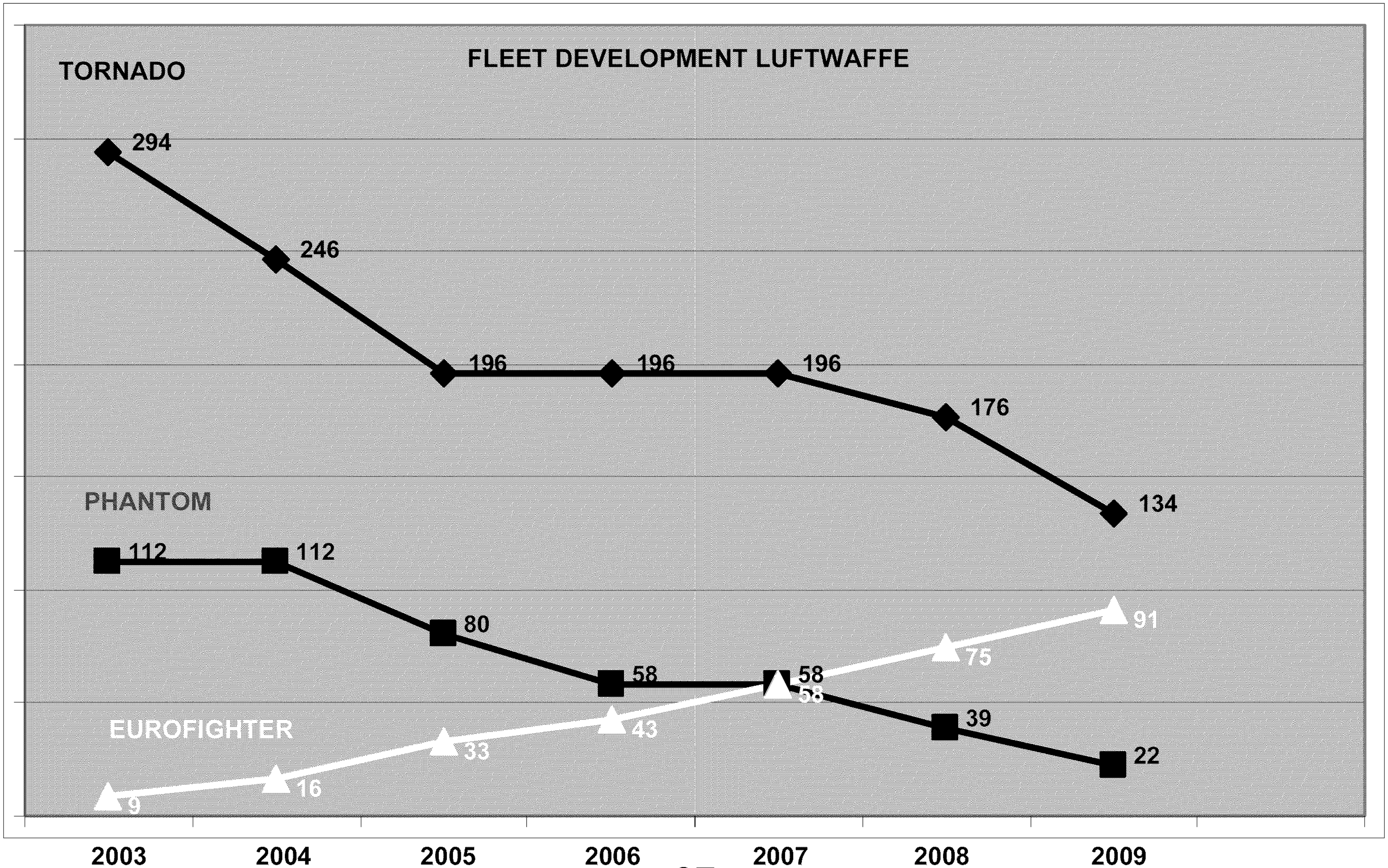
Qualification of Hydraulic Fluids

Mil-PRF-5606
- Qualification completed
- No restrictions determined

Mil-PRF-83282
- Ongoing, completion expected in Nov 2004
- Problems within the low-temperature range (-10°C)
  Undercarriage - Retraction time exceeding 31s (A/C Spec demands 6s)
  Undercarrige doors are overspeeded and damaged at 500kts (25s after Take-off)
- The introduction of MIL-PRF-83282 would entail limitations in the A/C Spec

Mil-PRF-87257
- Ongoing, completion expected in Nov 2004
- Minor Problems within the high-temperature range (+50°C)
  Increased Leakages due to low viscosity
- No restrictions determined yet

Decisions
- UK and GE decided the introduction of MIL-PRF-87257 in June 2004
- Decision from Spain and Italy outstanding



FLEET DEVELOPMENT LUFTWAFFE
TORNADO
294
246
196
196
196
176
134
PHANTOM
112
112
80
58
58
39
22
EUROFIGHTER
9
16
33
43
58
75
91
2003
2004
2005
2006
2007
2008
2009

97

DISCUSSION

NEW O-RING MATERIALS

15 June 2004

Alan Fletcher

Program Manager

Materials & Manufacturing Directorate

Air Force Research Laboratory

Problem – Existing Materials

- Aircraft service conditions have expanded operational temperature ranges beyond the capabilities of current o-ring materials (i.e., nitrile, fluorosilicone)
- Current materials are reasonably compatible with jet fuels and hydraulic fluids, but fail at low and high temperature extremes after prolonged fluid exposure
  - Low Temperature
    - Loss of elasticity with prolonged service
    - High compression set
    - Low sealing capacity
  - High Temperature
    - Thermal-chemical degradation
    - Physical breakdown of elastomer material
    - Loss of sealing capacity

Requirements - New Materials

- Performance across broad temperature range
  - -40 °F (-65 °F) to 225 °F/275 °F
- Low compression set at low temperature extremes
  - Before and after high temperature fluid exposure
- Primary fluid compatibility
  - MIL-H-83282 (275 °F)
  - MIL-H-87257 (275 °F)
  - JP-8 (225 °F)
  - JP-8+100 (225 °F)
    - Also JRF, MLI-PRF-5606 and MIL-PRF-23699
- Materials/systems compatibility

Program Goals

- Identify candidate materials with potential of meeting performance requirements
- Test candidate materials against performance criteria
  - MIL-P-83461 and MIL-P-5315
- Support development efforts required to enhance materials performance
  - Work with material providers
- Identify best performers
  - Make recommendations for replacement materials technologies and/or suppliers to the Air Force
- Qualify best performers

Materials

- Over 80 compounds identified for evaluation
  - Industry suppliers
    - Commercial materials
    - Experimental compounds
  - In-house efforts
    - Blending of existing materials
    - Synthesis of new materials
    - Additive technologies

Material Classifications

- Nitrile Rubbers (NBR)
- Hydrogenated Nitrile Rubbers (HNBR)
- Epichlorohydrin Rubbers (ECO)
- Fluorosilicones (FVMQ)
- Fluoroelastomers (FKM)
- Perfluoroethers (PFE)
- PFE-Vinylidene Fluoride Rubbers (PFE-VF)
- Experimental Fluoroelastomers (X-FKM)

Testing and Evaluation

- Tier I - Screening Tests
  - 43 materials tested extensively
    - Compression molded test plaques
    - Greater sample availability
- Tier II - O-ring Testing
  - Best performers from Tier I
  - 23 materials tested extensively
- Tier III - Final Qualification Testing
  - Three (3) best performing o-ring materials

Tier I Testing - Plaques

- High temperature fluid aging
  - 3 and 28-day immersion in jet fuels at 225 °F
    - JP8, JP8+100
  - 3 and 28-day immersion in hydraulic fluids at 275 °F
    - MIL-PRF-83282, MIL-PRF-87257
- Material characterization – before and after fluid aging
  - Volume swell, weight gain, % extracted material, hardness
    - ASTM D471, *Test Method for Rubber Property – Effects of Liquids*
  - Tensile property characterization
    - ASTM D412, *Rubber Properties in Tension*
  - Compression set measurements
    - Room Temperature (RT) - *ASTM D 395, Standard Test Methods for Rubber Property - Compression Set*
    - -40 °F - *ASTM D 1229, Standard Test Methods for Rubber Property - Compression Set at Low Temperatures*

Tier II Testing – O-rings

- High temperature fluid aging
  - 3 and 28-day immersion in jet fuels at 225 °F
    - JP8, JP8+100
  - 3 and 28-day immersion in hydraulic fluids at 275 °F
    - MIL-PRF-83282, MIL-PRF-87257
- O-ring characterization – before and after fluid aging
  - Volume swell, weight gain, % extracted material, hardness
    - ASTM D471, *Test Method for Rubber Property – Effects of Liquids*
  - Physical property characterization
    - ASTM D 1414, *Standard Test Method for Rubber O-Rings*
      - Tensile properties
      - Compression set @ RT, -40 °F and -65 °F
  - Compression stress relaxation (CSR) measurements
    - ASTM D6147, *Test Method of Vulcanized Rubber and Thermoplastic Elastomer – Determination of Force Decay (Stress Relaxation) in Compression.*

Tier III Testing – Final

- High temperature fluid aging
  - 3 day immersion in jet fuels at 225 °F
    - JRF, JP8+100, JRF
  - 3 day immersion in hydraulic fluids at 275 °F
    - MIL-PRF-83282, MIL-PRF-87257, MIL-PRF-5606, MIL-PRF-23699
- O-ring testing - before and after fluid aging
  - Volume swell, weight gain, % extracted material, hardness
  - Physical property characterization
  - Compression set @ RT and -40 °F
    - Repeated after 60-day aging in air
- Corrosion and adhesion testing
  - MIL-P-83461, Section 4.6.3
- Compression stress relaxation measurements
- Dynamic testing
  - MIL-P-83461, Section 3.3.3
- Third party data verification

Performance Criteria

- High temperature fluid resistance
  - < 15% volume swell
  - Minimal amount of extracted material
- Good physical property performance
  - > 1000 psi tensile
  - > 125% elongation
  - > 50% retention of properties after fluid aging
- Reasonable hardness values
  - Shore A 60 to 80
  - < 10 point hardness change after fluid aging
- Good low temperature compression set resistance
  - < 50% before and after fluid aging
- Good sealing performance
  - Based on CSR testing

Summary of Performance

- Best Performers
  - PFE-VF
  - PFE
  - X-FKM
- General comments on other materials
  - NBR and HNBR - weight loss, volume swell, property retention, poor low T performance (CS and CSR)
  - FVMQ - weight loss, properties/property retention
  - FKM - poor low T performance (CS and CSR), properties/property retention
  - ECO - high CS after aging, weight loss, property retention

NBR-L (3-Day Fluid Aging)

Sample		Weight Gain	Volume Change	RT C-Set	-40 °F C-Set	Break Stress	ΔBreak Stress	Elong @Break	ΔElong @Break
		%	%	%	%	psi	%	%	%
Control	Mean			9.8	81.0	2442.66		324.29	
	σ			**0.9**	**4.2**	**356.62**		**42.98**	
JP-8+100	Mean	14.0	19.0	73.5	86.8	1600.86	-34.5	267.40	-17.5
	σ	**0.2**	**0.0**	**1.8**	**6.2**	**122.81**		**7.05**	
JRF	Mean	10.7	16.4	52.4	59.0	664.66	-72.8	191.31	-41.0
	σ	**0.2**	**0.3**	**1.8**	**5.7**	**77.96**		**13.28**	
83282	Mean	7.3	9.3	87.5	101.7	1761.76	-27.9	237.20	-26.9
	σ	**0.1**	**0.2**	**3.4**	**1.5**	**91.13**		**10.60**	
87257	Mean	9.8	12.6	82.6	99.3	623.89	-74.6	113.85	-4.9
	σ	**0.1**	**0.2**	**3.7**	**1.5**	**6.16**		**3.60**	
5606	Mean	11.7	15.6	44.6	82.9	793.64	-67.5	164.40	-49.3
	σ	**0.1**	**0.1**	**4.4**	**7.2**	**301.82**		**37.90**	
23699	Mean	22.9	26.4	28.7	59.5	884.21	-63.8	185.57	-42.8
	σ	**0.4**	**0.6**	**2.1**	**1.1**	**231.98**		**31.97**	

PFE-VF (3-Day Fluid Aging)

Sample		Weight Gain	Volume Change	RT C-Set	-40 °F C-Set	Break Stress	ΔBreak Stress	Elong @Break	ΔElong @Break
		%	%	%	%	psi	%	%	%
Control	Mean			11.1	73.8	1588.49		209.21	
	σ			**0.7**	**9.3**	**197.39**		**15.41**	
JP-8+100	Mean	1.7	4.8	22.4	77.1	1378.44	-13.2	205.84	-1.6
	σ	**0.1**	**0.1**	**0.2**	**0.9**	**139.94**		**21.14**	
JRF	Mean	4.1	10.8	15.7	67.1	1273.91	-19.8	197.91	-5.4
	σ	**0.2**	**0.3**	**1.5**	**0.9**	**103.97**		**7.78**	
83282	Mean	1.1	3.2	30.9	77.3	1633.94	2.9	206.71	-1.2
	σ	**0.1**	**0.3**	**6.0**	**1.0**	**95.25**		**12.03**	
87257	Mean	1.4	4.3	29.3	79.2	1283.23	-19.2	200.93	-4.0
	σ	**0.1**	**0.3**	**11.7**	**3.5**	**208.43**		**23.39**	
5606	Mean	1.8	4.7	28.7	78.3	1594.91	0.4	205.97	-1.5
	σ	**0.0**	**0.4**	**2.3**	**4.6**	**7.47**		**24.07**	
23699	Mean	1.3	3.7	28.6	76.3	1454.20	-8.5	207.05	-1.0
	σ	**0.0**	**0.1**	**1.8**	**5.4**	**17.42**		**3.48**	

PFE (3-Day Fluid Aging)

Sample		Weight Gain	Volume Change	RT C-Set	-40 °F C-Set	Break Stress	ΔBreak Stress	Elong @Break	ΔElong @Break
		%	%	%	%	psi	%	%	%
Control	Mean			2.3	14.8	1137.28		147.69	
	σ			**0.3**	**1.6**	**205.04**		**15.29**	
JP-8+100	Mean	2.7	6.1	1.2	5.9	957.19	-15.8	132.60	-10.2
	σ	**0.0**	**0.2**	**1.4**	**1.0**	**186.70**		**15.47**	
JRF	Mean	6.0	14.9	-4.9	-2.3	870.99	-23.4	129.38	-12.4
	σ	**0.0**	**0.4**	**1.0**	**1.1**	**36.16**		**5.15**	
83282	Mean	0.5	2.0	6.9	22.5	1228.85	8.1	156.05	5.7
	σ	**0.0**	**0.1**	**0.3**	**3.3**	**138.66**		**7.80**	
87257	Mean	1.0	3.3	5.5	15.3	1226.51	7.8	156.59	6.0
	σ	**0.0**	**0.2**	**0.6**	**1.0**	**26.90**		**3.77**	
5606	Mean	2.5	6.6	4.4	11.1	871.22	-23.4	128.20	-13.2
	σ	**0.0**	**0.2**	**3.2**	**0.3**	**176.14**		**13.61**	
23699	Mean	0.4	1.7	12.8	22.5	1064.64	-6.4	140.02	-5.2
	σ	**0.0**	**0.2**	**2.5**	**2.7**	**75.80**		**6.07**	

X-FKM (3-Day Fluid Aging)

Test Condition		Weight Gain	Volume Change	RT C-Set	-40 °F C-Set	Break Stress	ΔBreak Stress	Elong @Break	ΔElong @Break
		%	%	%	%	psi	%	%	%
Control	Mean			2.5	19.2	1123.74		230.37	
	σ			**0.1**	**0.5**	**80.85**		**1.54**	
JP-8+100	Mean	2.6	6.5	2.5	10.9	797.85	-29.0	187.01	-18.8
	σ	**0.0**	**0.5**	**0.1**	**4.5**	**106.09**		**17.86**	
83282	Mean	0.6	1.8	11.3	26.5	877.67	-21.9	203.19	-11.8
	σ	**0.0**	**0.5**	**0.4**	**0.2**	**2.70**		**1.04**	

Compression Set (60-day @ RT)

Test Condition		Air		JP-8+100		MIL-PRF-83282	
		RT C-Set	-40° F C-Set	RT C-Set	-40° F C-Set	RT C-Set	-40° F C-Set
		%	%	%	%	%	%
PFE-VF	Mean	11.3	84.5	8.8	83.1	11.1	76.2
	σ	0.8	3.1	0.2	4.5	0.9	5.9
PFE	Mean	1.4	32.1	-1.7	6.3	1.9	24.7
	σ	0.3	2.3	0.3	0.7	0.2	1.5
X-FKM	Mean	2.3	21.0	0.4	7.6	2.3	19.1
	σ	0.6	0.3	0.7	2.1	0.6	4.7

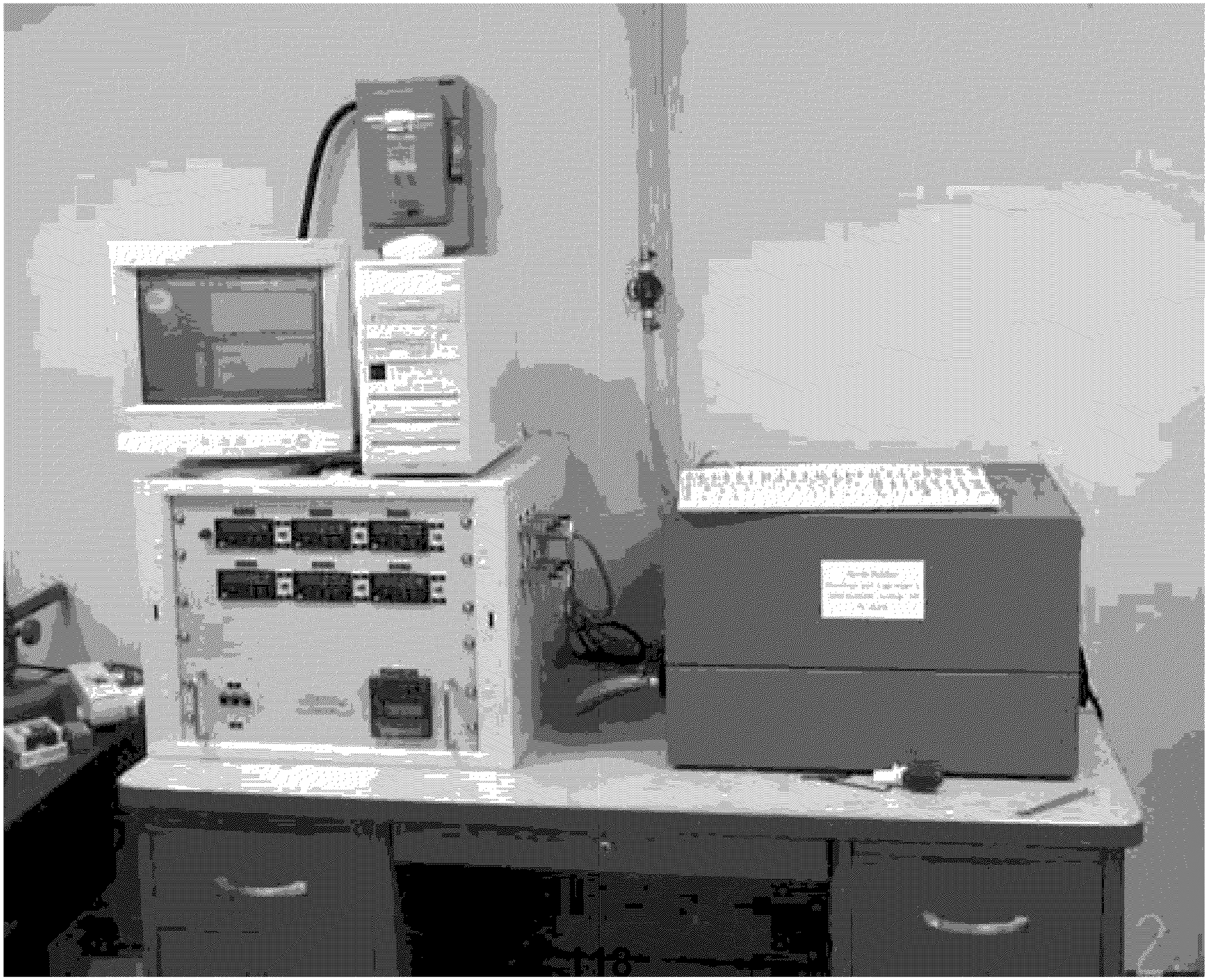
Compression Stress Relaxation Measurements

- Compression set testing provided limited insights into low temperature performance
  - Values were generally high even for better materials
  - Exceeded 100% for poor materials (plastic flow)
- Compression stress relaxation (CSR) testing required to best characterize sealing performance
  - *In situ* measurement provide means of monitoring sealing performance before, during and after fluid aging at temperatures of interest

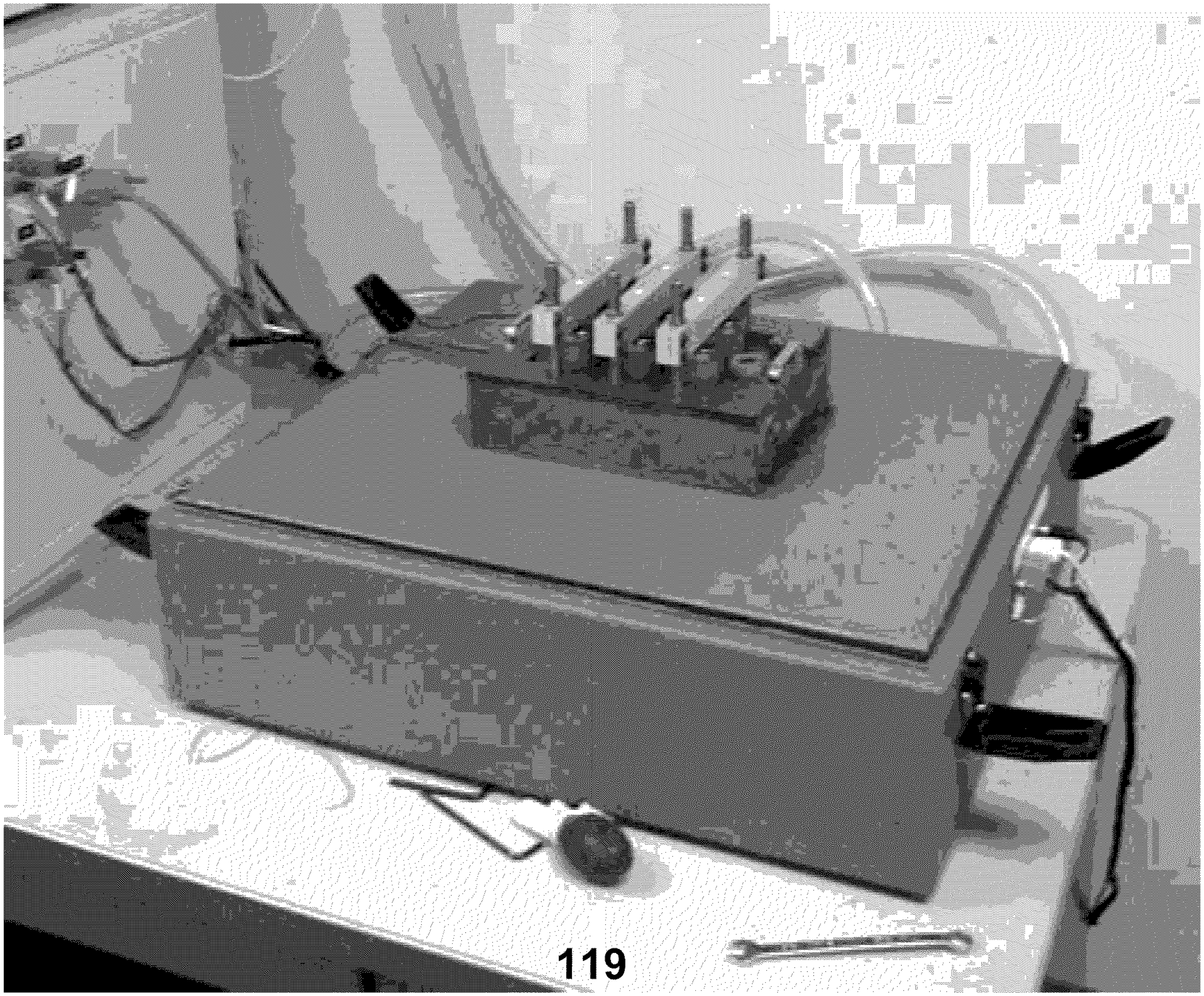
CSR Test Equipment

- METSS CSR unit custom built by Akron Rubber Development Laboratory (ARDL)
- Temperature range of -55 to 350 °F @ ± 2 °F
- Immersion bath for *in situ* fluid aging
- Test 6 o-rings at once; generally 3 sets of 2
- Constant strain load configuration
- Constant force monitoring

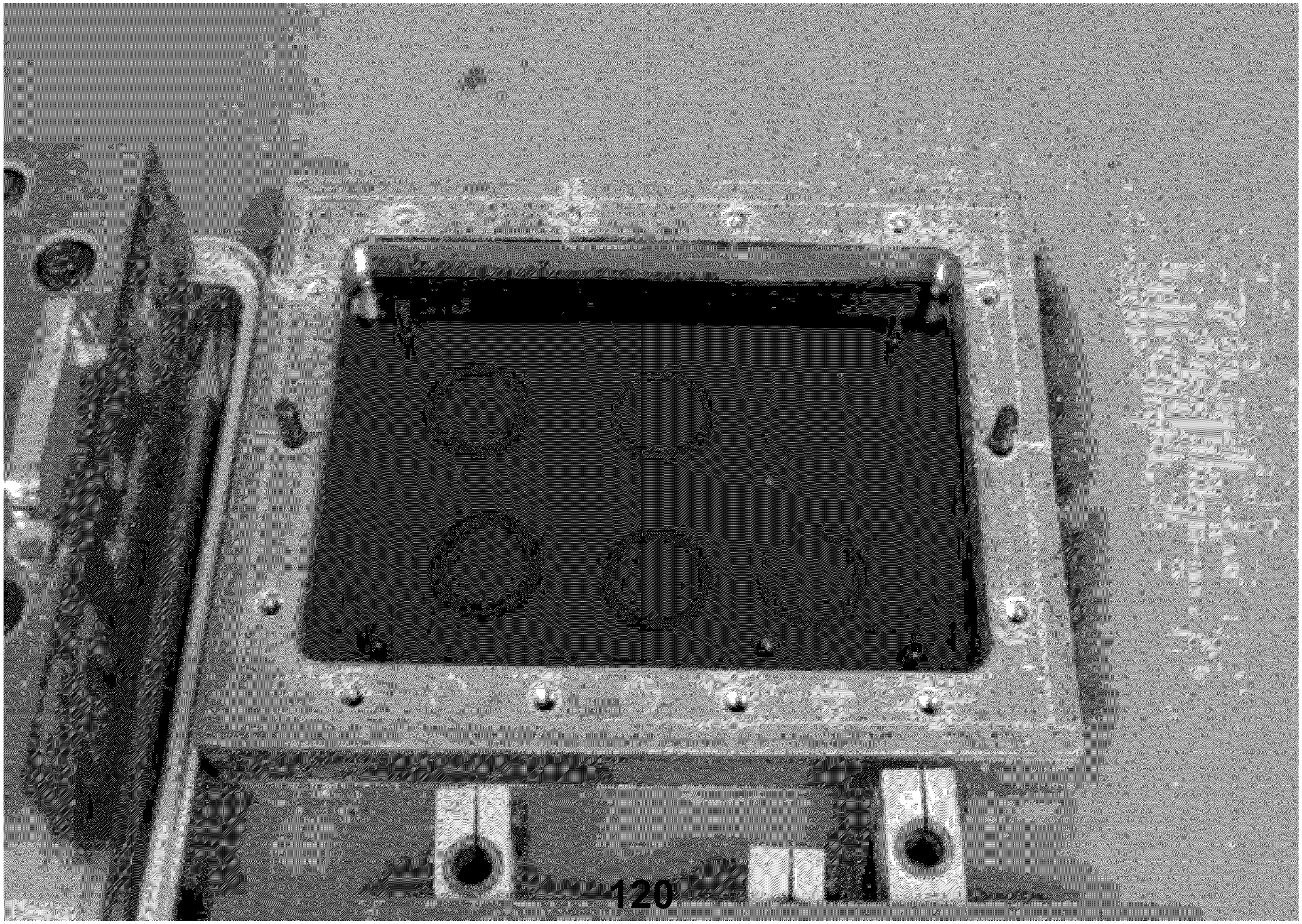
CSR Testing Unit



CSR Load Cell Configuration



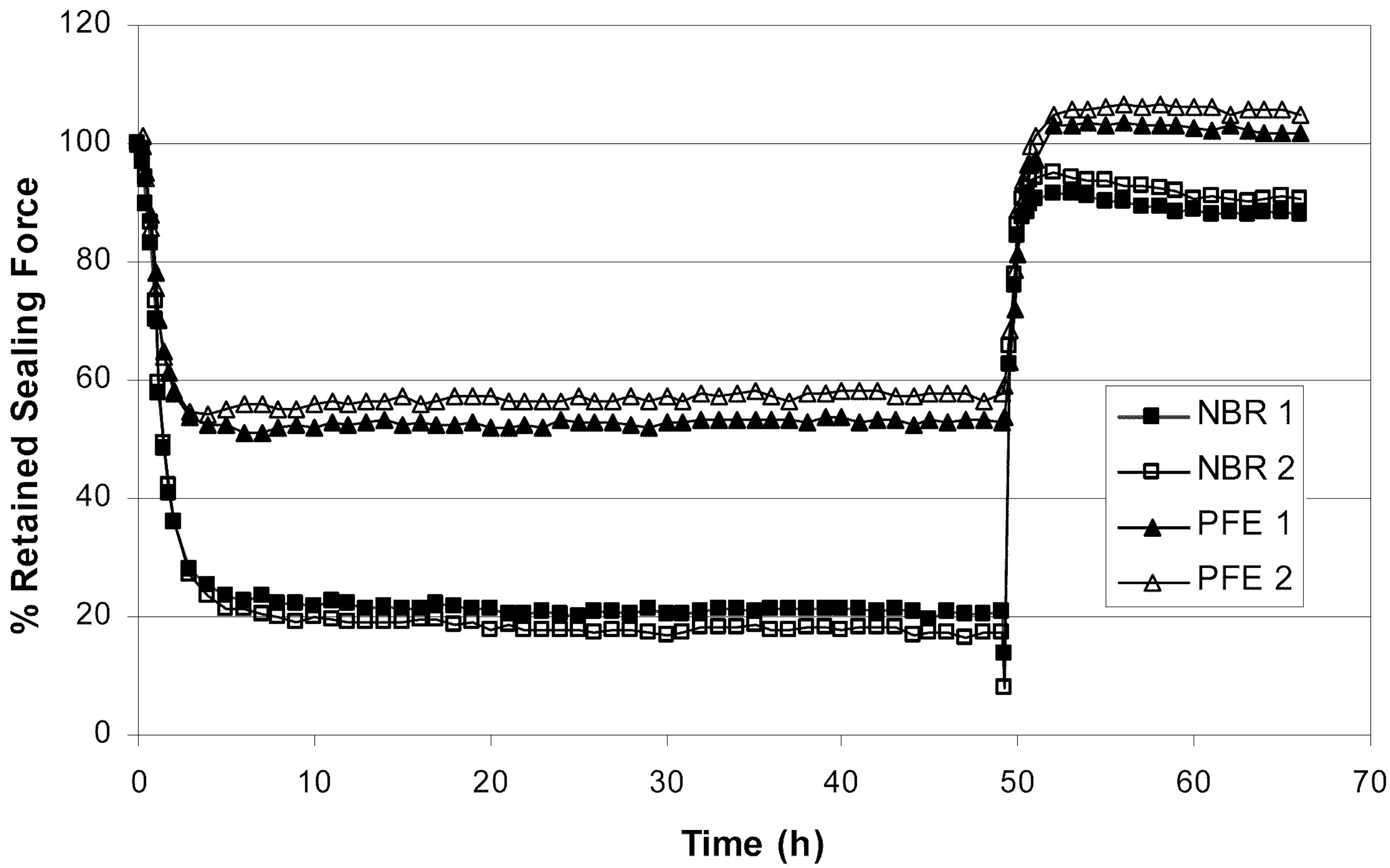
CSR Fluid Bath



CSR Test Profile 1

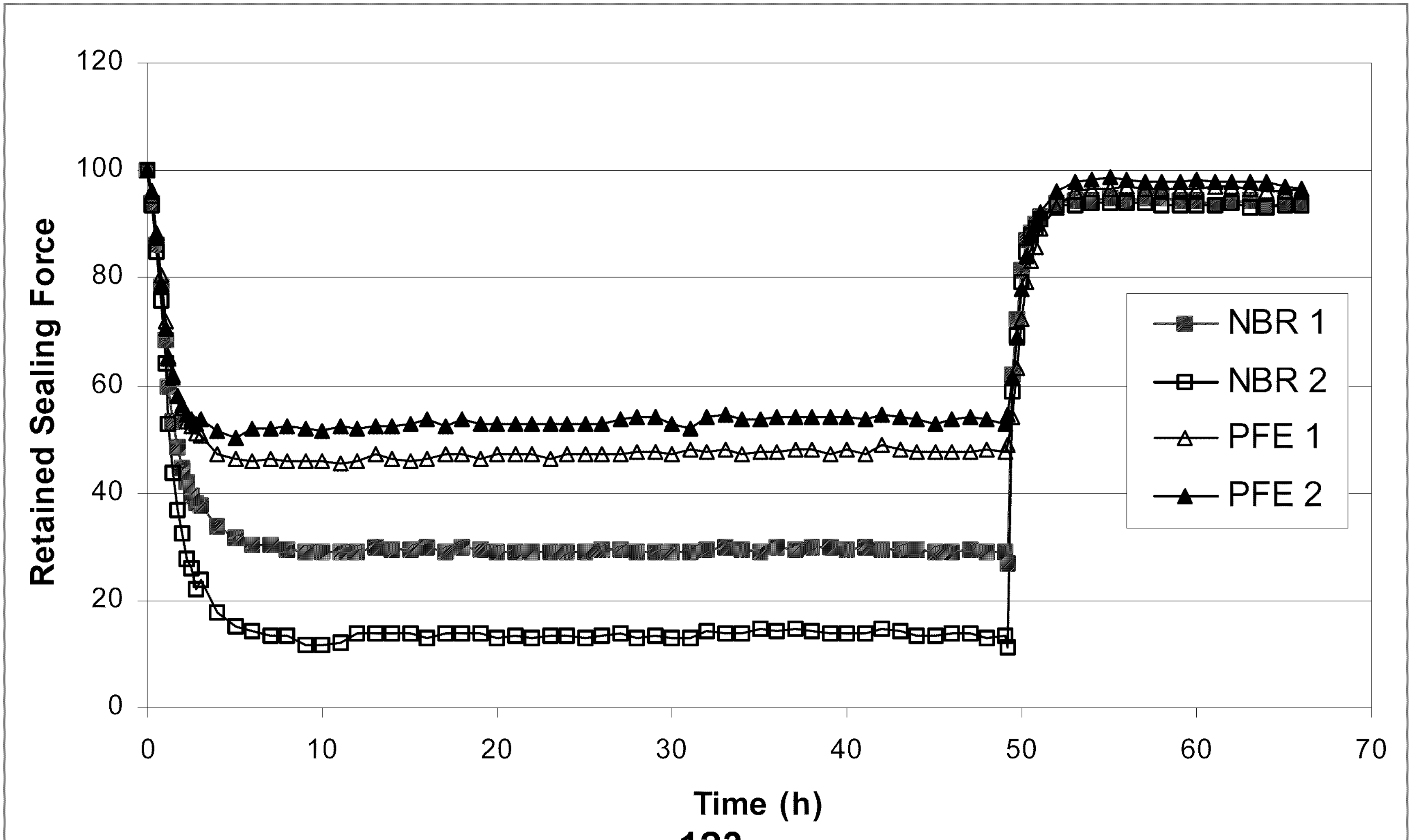
- O-rings aged external to CSR unit
  - NBR-L and PFE aged 3 days in fluid at 225 ºF / 275 ºF
- O-rings placed in CSR unit
  - Immersed in aging fluid
  - Compressed to 25% strain at RT
- Temperature profile
  - Temperature equilibrated at 77 ºF
  - Samples cooled to -40 ºF over a period of 1 hour
  - Temperature held at -40 °F for 48 hours
  - Samples heated to 77 ºF over a period of 1 hour
  - Temperature held at 77 °F for 48 hours
- Sealing force normalized and plotted as a function of time

CSR 1 (unaged)

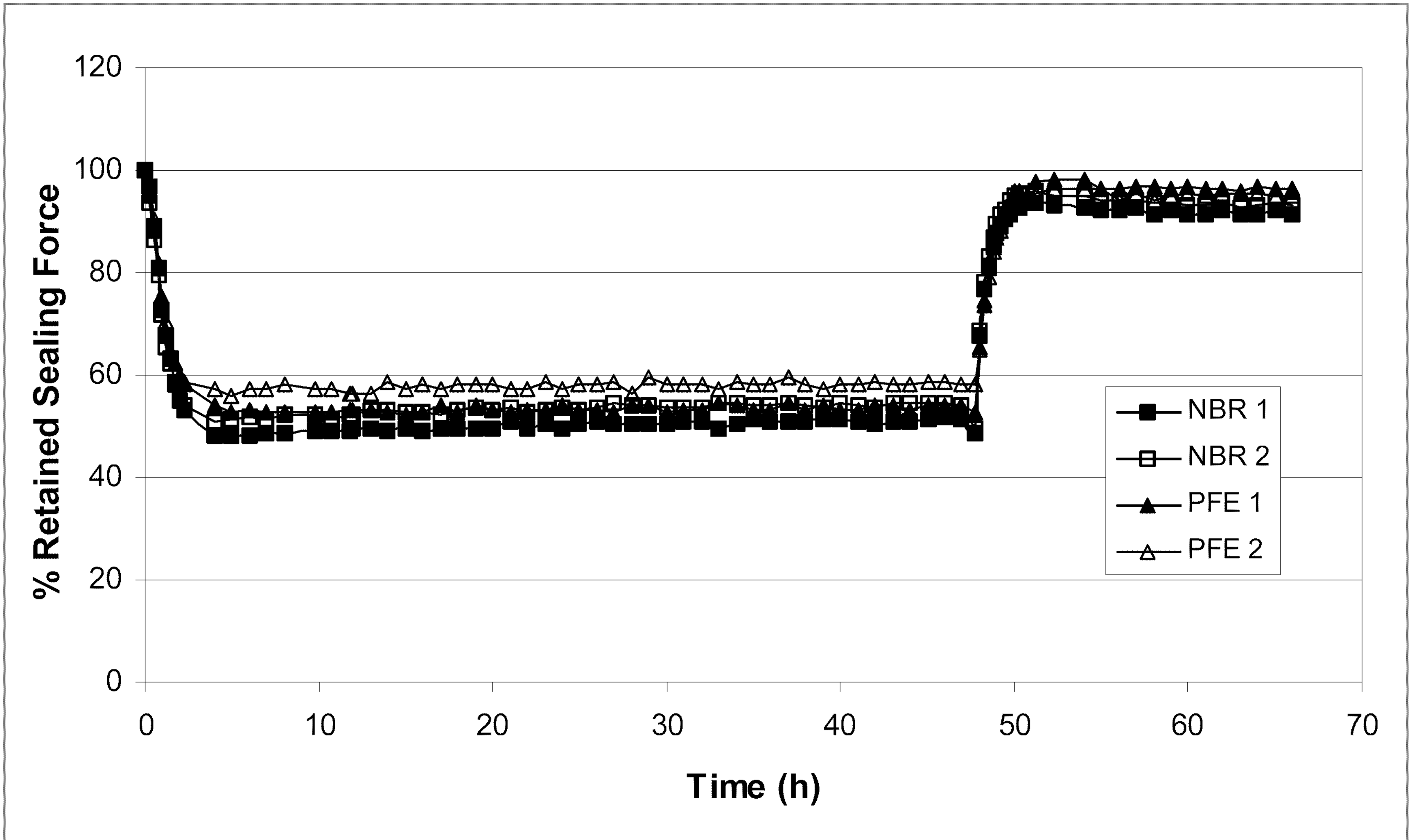


120
100
80
60
40
20
0
% Retained Sealing Force
0
10
20
30
40
50
60
70
Time (h)
NBR 1
NBR 2
PFE 1
PFE 2

CSR 1 (MIL-PRF-83282)



CSR 1 (JP8+100)

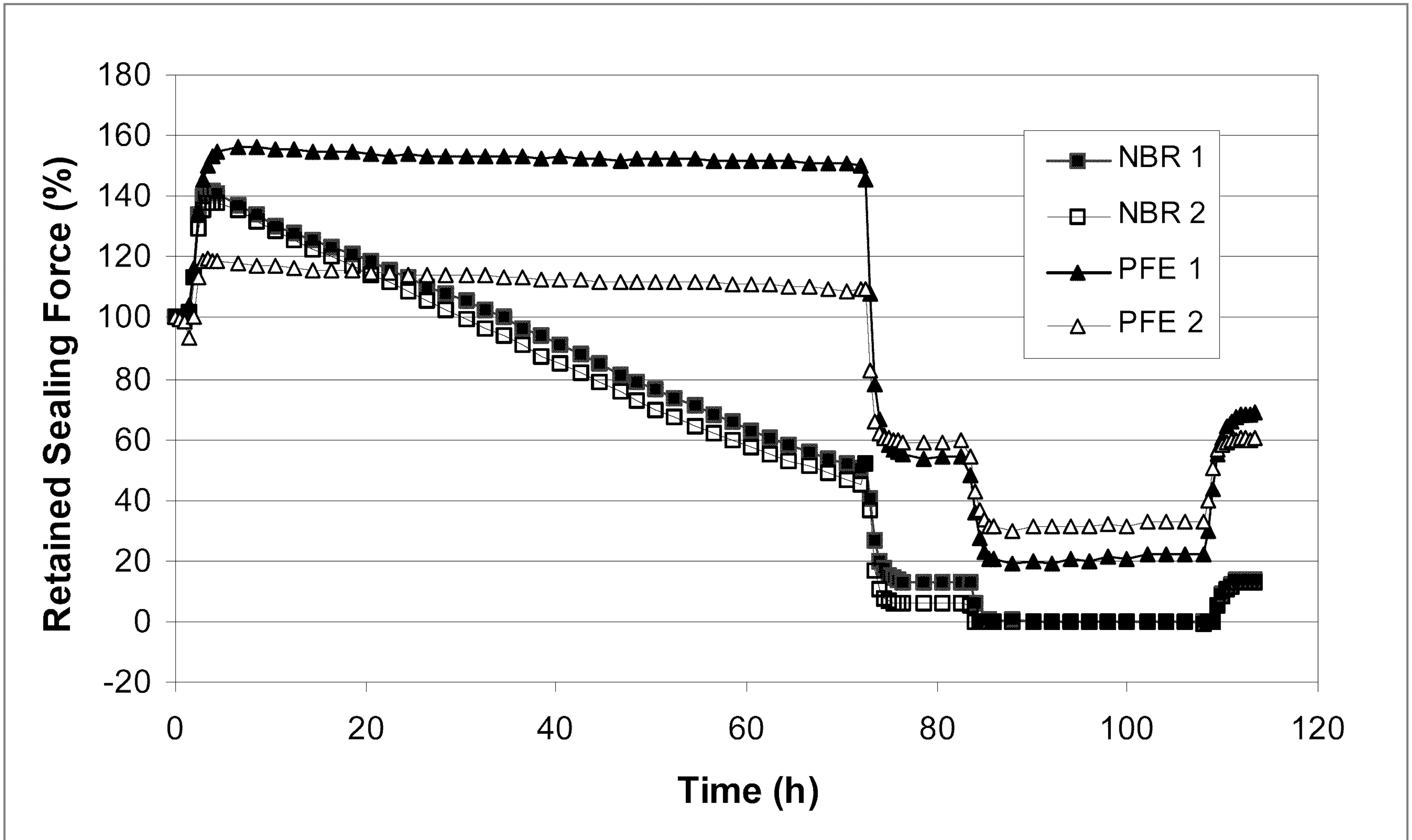


% Retained Sealing Force
120
100
80
60
40
20
0
0
10
20
30
40
50
60
70
Time (h)
NBR 1
NBR 2
PFE 1
PFE 2

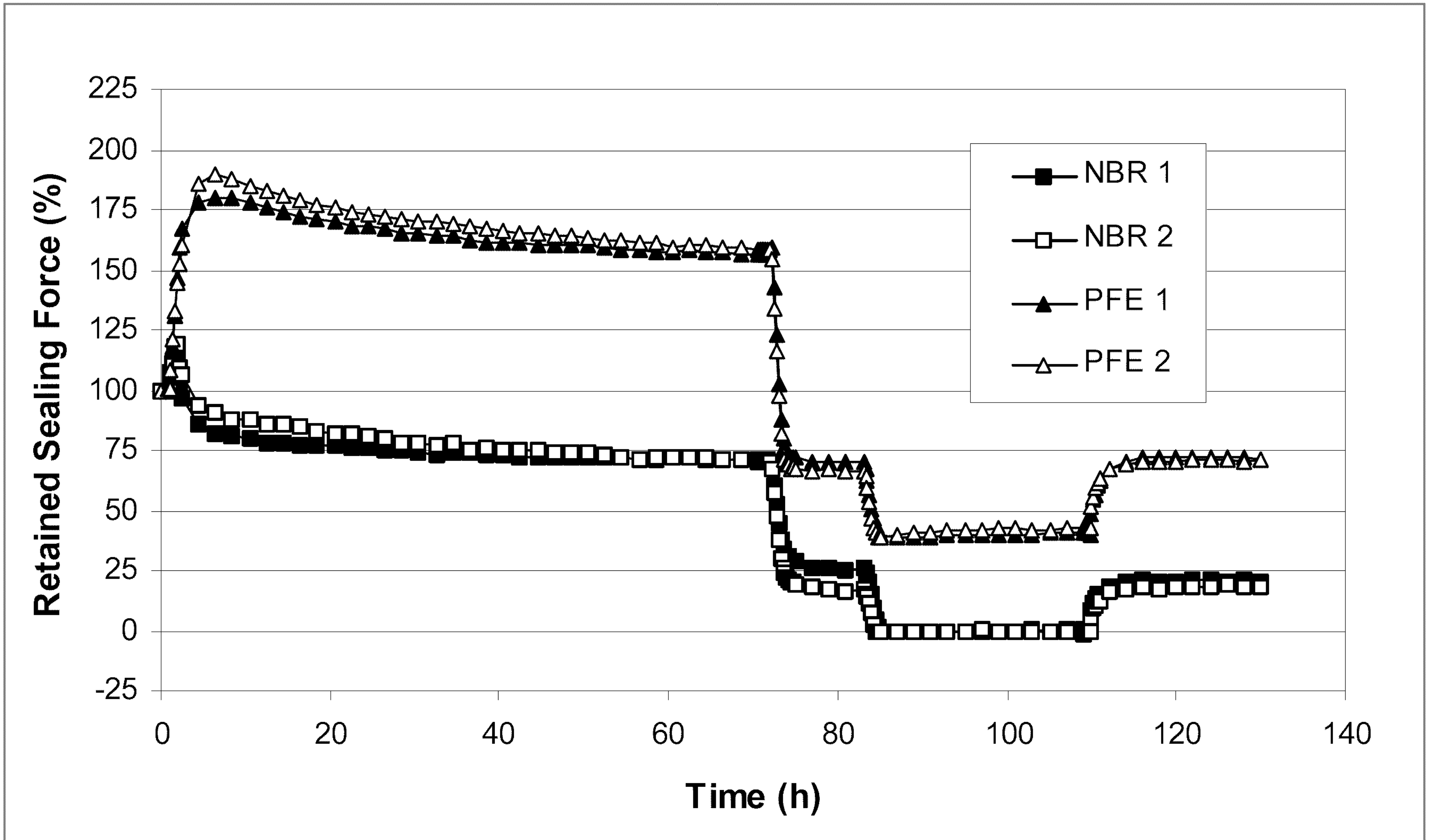
CSR Test Profile 2

- O-rings aged *in situ* in CSR unit
  - Immersed in fluid
  - Compressed to 25% strain at RT
- Temperature profile
  - Temperature equilibrated at 77 ºF
  - Temperature ramped to the aging temperature over 1 hour
  - Temperature held at the fluid aging temperature for 70 hours
  - Temperature cooled to 77 ºF over a period of 1 hour
  - Temperature held at 77 ºF for 10 hours
  - Temperature cooled to -40 °F over a period of 1 hour
  - Temperature held at -40 °F for 48 hours
  - Temperature ramped up to 77 ºF over a period of 1 hour
  - Temperature held at 77 ºF for 1 hour
- Sealing force normalized and plotted as a function of time

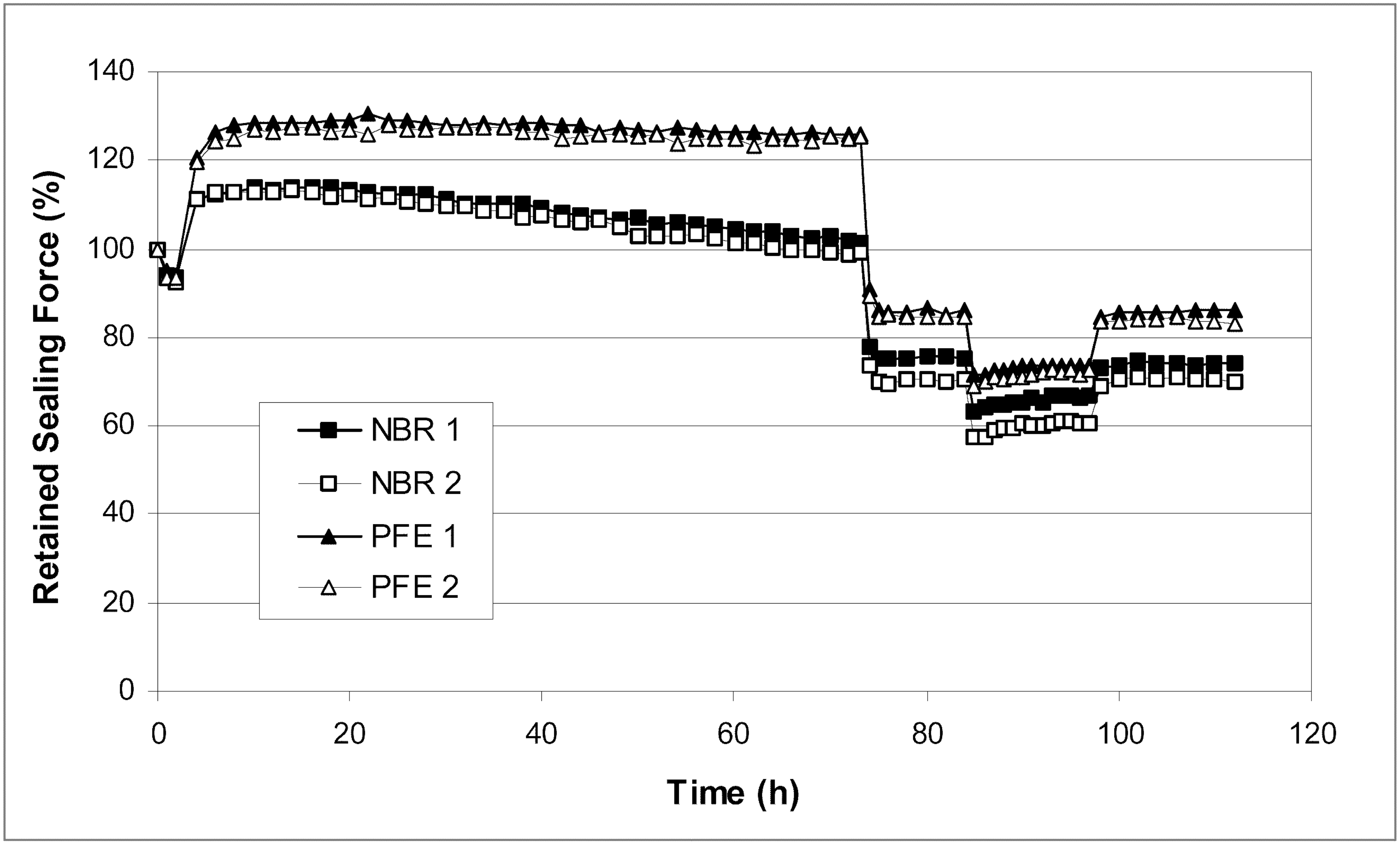
CSR 2 (275 °F in Air)



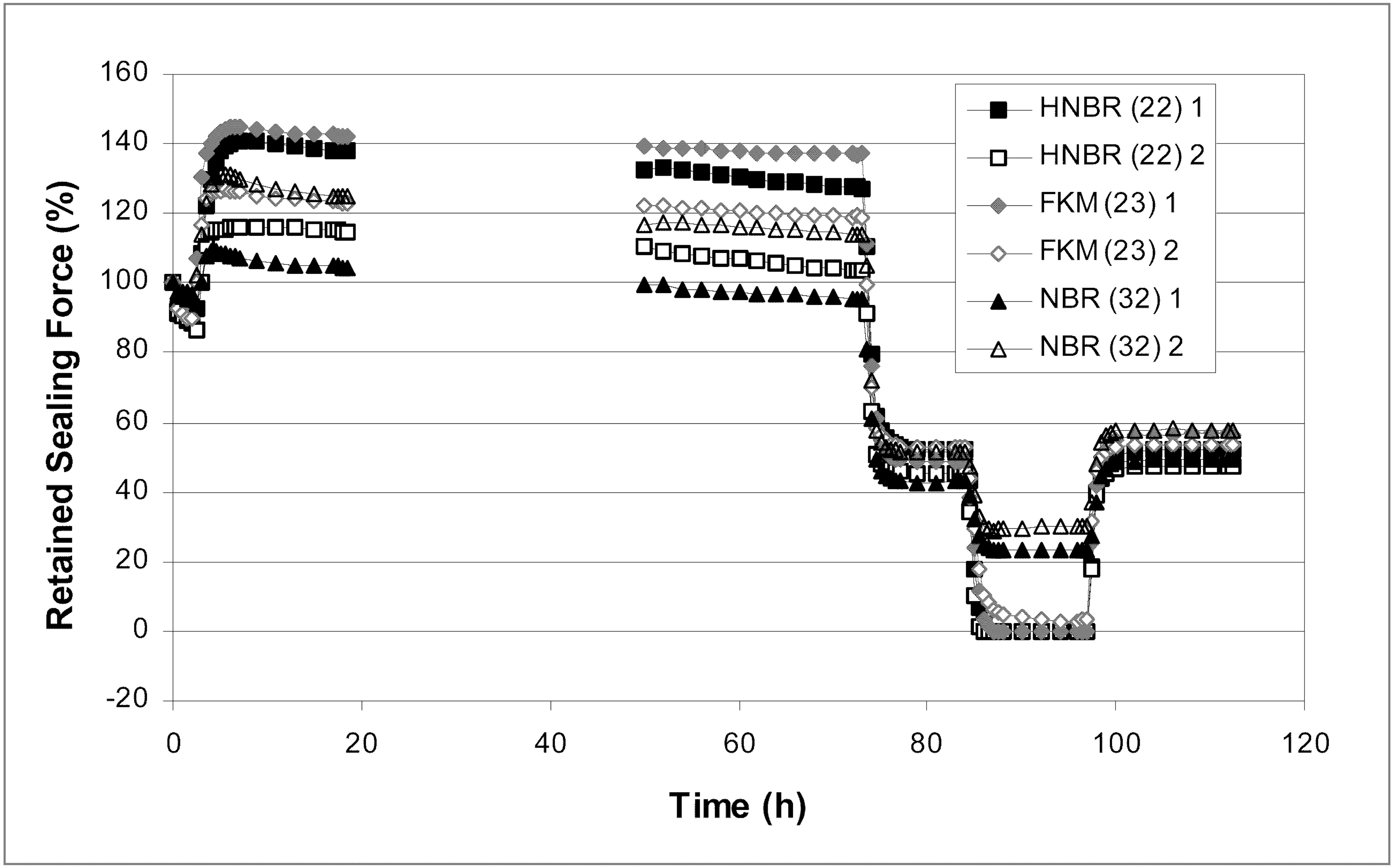
CSR 2 (275 °F 83282)



CSR 2 (255 °F JP-8+100)

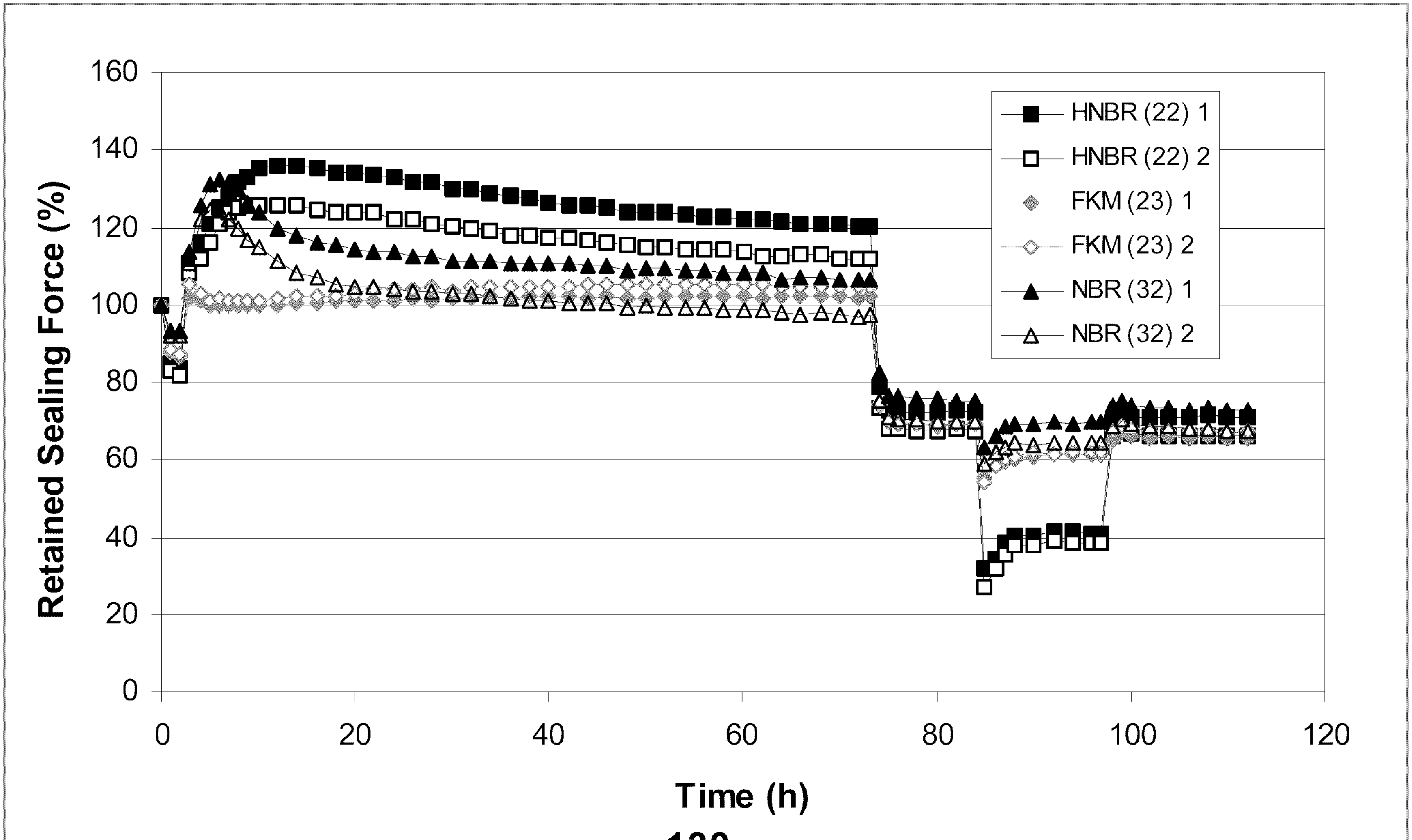


CSR 2 (275 °F 83282)



129

CSR 2 (255 °F JP-8+100)



Final Testing - Best Performers

- New set of o-rings
  - Final commercial compounds
- Third party testing
  - Verification of in-house testing
  - Dynamic seal testing
    - MIL-P-83461, Section 3.3.3
- Additional CSR Testing

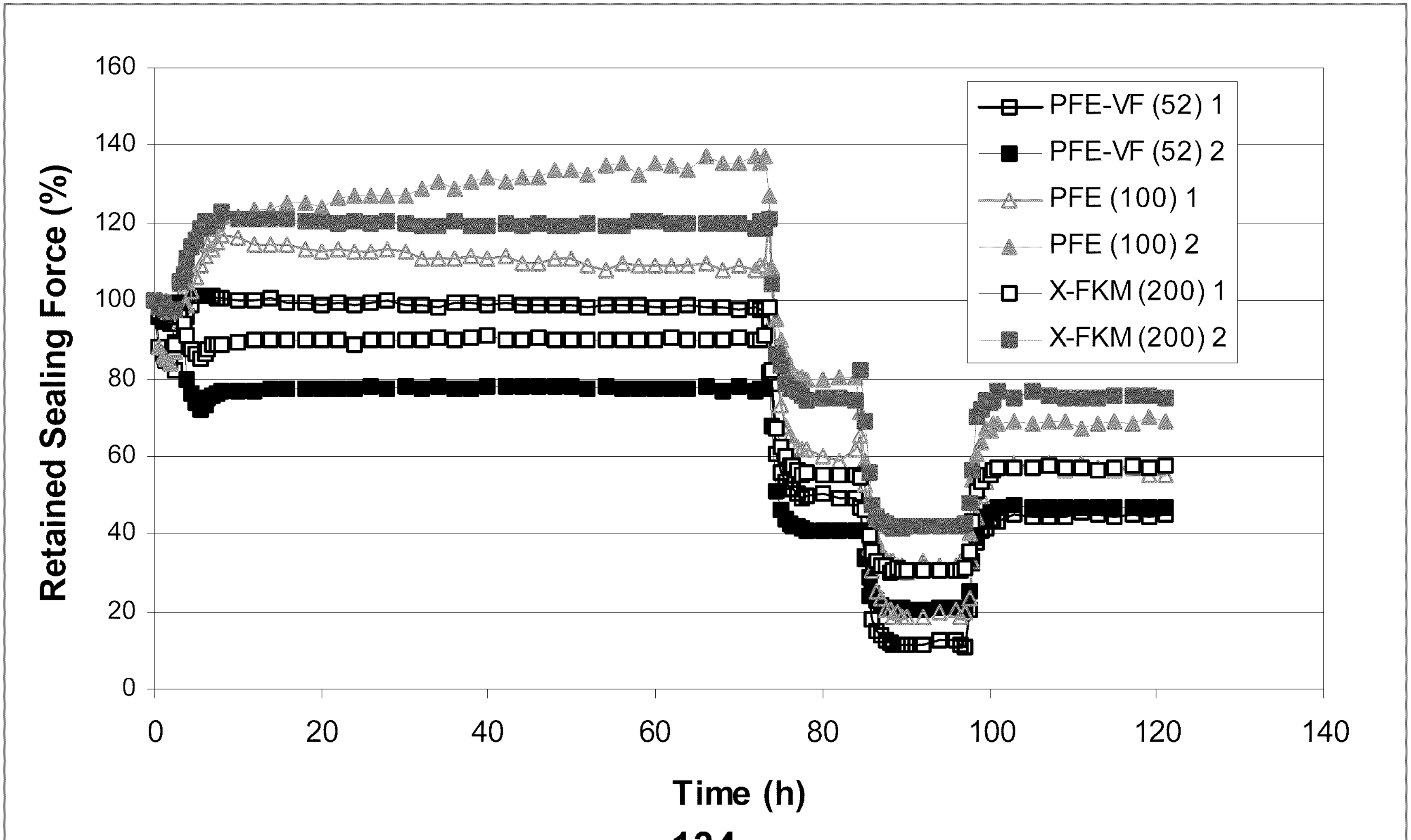
Third Party Test Data

	PFE-VF	PFE	X-FKM
Initial Properties			
Hardness	70	71	58
Tensile Strength (psi)	1405	1010	908
Tensile Elongation (%)	134.4	119.3	163.9
Compression Set (RT)	16.7	10.3	4.4
Compression Set (-40 °F)	35.7	25.0	36.8
Compression Set (-65 °F)	51.5	41.2	44.2
After 3 Days in Air @ 275 °F			
Compression Set (RT)	27.2	8.8	5.9
Compression Set (-40 °F)	35.7	22.1	10.3
Compression Set (-65 °F)	70.0	54.4	35.3

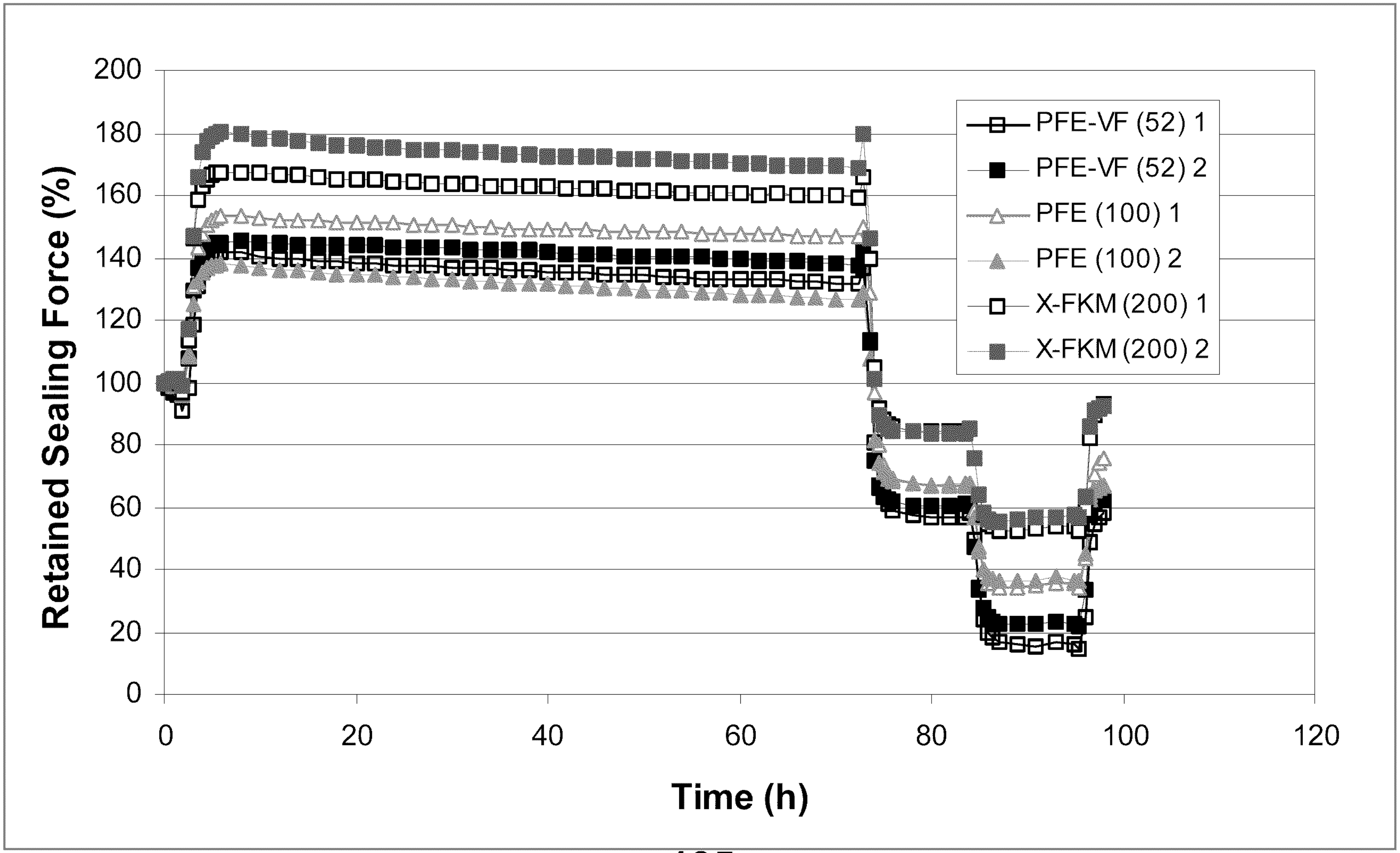
Third Party Test Data

	PFE-VF	PFE	X-FKM
After 3 Days in MIL-PRF-83282 @ 275 °F			
Volume Swell (%)	2.6	1.7	1.1
Change in Hardness	0	2	0
Change in Tensile Strength (%)	-1.9	+13.6	+38.9
Change in Tensile Elongation (%)	+4.8	+2.9	+15.9
Compression Set (RT)	14.7	10.3	13.3
Compression Set (-40 °F)	52.9	17.7	25.0
Compression Set (-65 °F)	73.6	47.1	36.8
After 3 Days in JP-8+100 @ 225 °F			
Volume Swell (%)	3.9	7.2	6.1
Change in Hardness	-1	-5	-4
Change in Tensile Strength (%)	-6.4	+6.5	+7.1
Change in Tensile Elongation (%)	-8.3	+4.3	+4.2
Compression Set (RT)	10.3	5.9	7.4
Compression Set (-40 °F)	64.7	25.0	22.1
Compression Set (-65 °F)	76.5	31.0	27.9

CSR-2 (Best O-rings in Air)

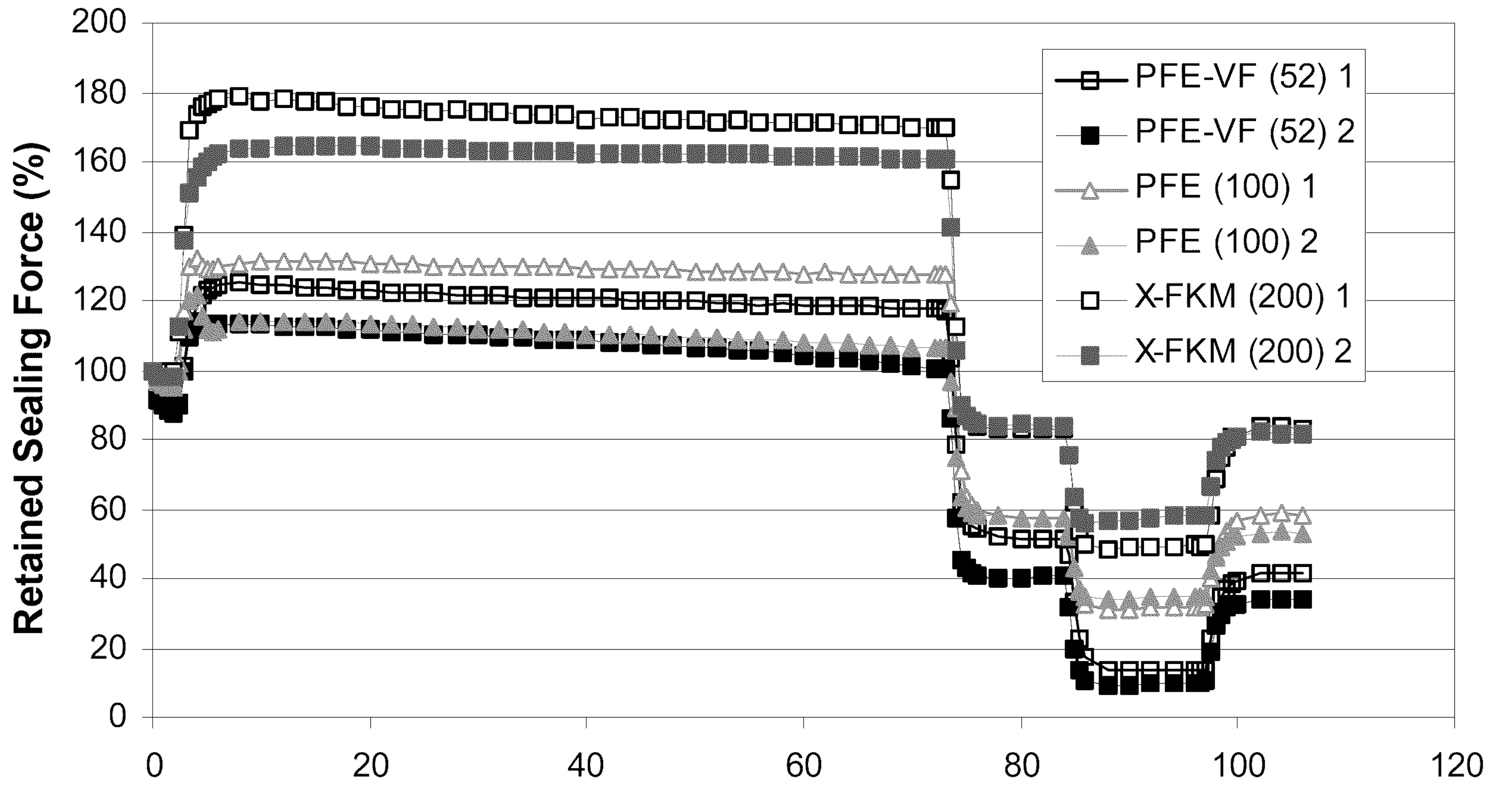


CSR-2 (Best O-rings in 83282)



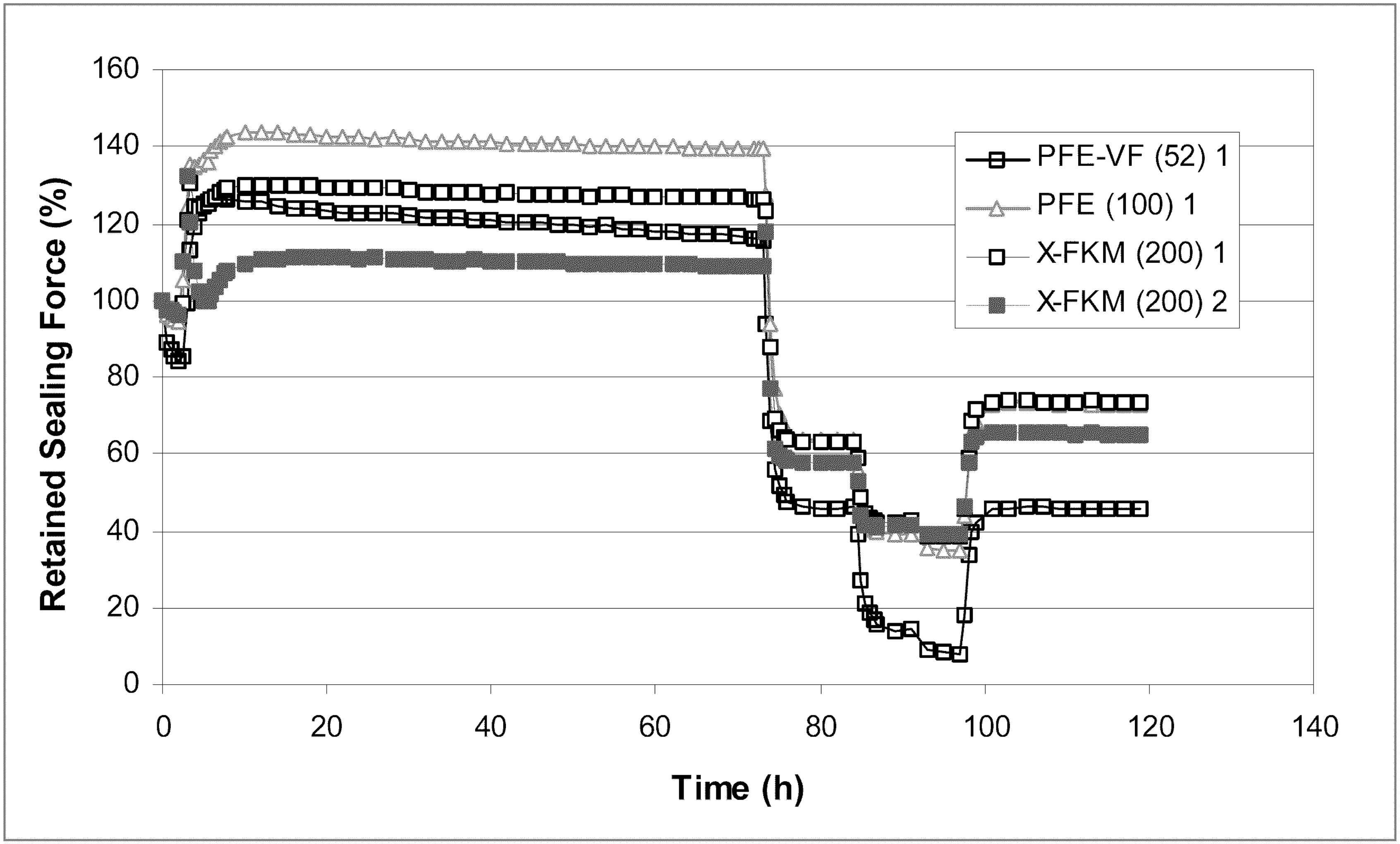
135

CSR-2 (Best O-rings in 87257)

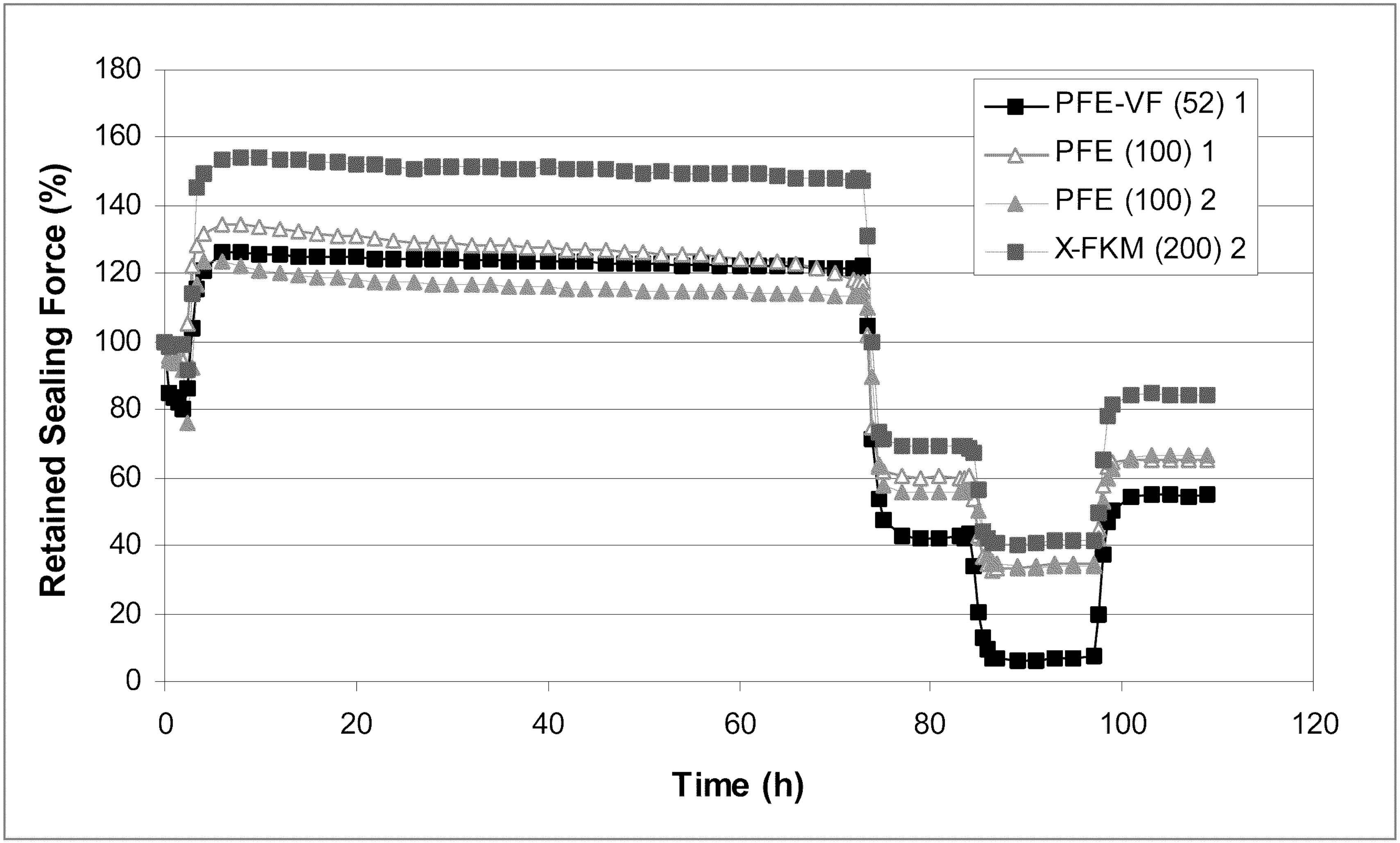


136

CSR-2 (Best O-rings in 5606)



CSR-2 (Best O-rings in 23699)



138

Concluding Remarks

- Best Performers
  - PFE-VF
  - PFE
  - X-FKM
- All of these materials are now commercially available
- No problems with corrosion or adhesion
- None of the materials passed dynamic testing
  - Recommended for static sealing applications only
- CSR testing provided best insights into low temperature sealing capability and service performance
  - CSR unit currently available for outside testing

Backup

backup

Fuel Coupling Test Program

Fuel Coupling Test Program

Overview

- Purpose of Test
- Background /Previous Testing and Results
- Test Stand Development / Capabilities
- Test Materials and Fuel
- Test Procedures and Values
- Test Result Evaluation Criteria
- Test Results (Coupling Leakage)
  - 225°F Aging Results at 7 Days (JP-8)
  - 225°F Aging Results at 7 Days (JP-8 + 100)
  - 325°F Aging Results at 7 Days (JP-8)
  - 325°F Aging Results to Failure (Incomplete) (JP-8)
- Conclusions (Preliminary) Testing Incomplete
- Recommendations (Preliminary) Testing Incomplete

Test Purpose

- Compare service life of various existing O-ring materials to recently developed (new materials) as installed in an aircraft fuel line couplings.
- Under same environmental conditions
  - Combined test fixture and environmental chamber
  - Aging temperature time
  - Leakage temperature test variations
- Under same test pressure
- With two different coupling types
  - Fixed cavity couplings (F-16 Type)
  - Variable cavity couplings (F-15 Type)

Test Program

- Existing materials (system shakedown)
  - Limited aging time (7 days) at 225°F and 325°F
- New and existing (high tech material)
  - To failure (failure determined by coupling leakage at 325°F to low temperature ranging from room temperature to – 65°F after 325°F high temperature aging in 7 day increments)

Background/Previous Testing and Result

Previous Testing:

- O-Ring materials physical properties testing (tensile, elongation, compression set, volume swell and hardness)
- Test Stand developed to evaluate o-ring performance in fuel line couplings:
  - Fuel system coupling tests (7 day and 28 day fuel aging at 225ºF and 325ºF temperature)
  - Variable cavity couplings and fixed cavity couplings with circulating fuel.
  - Measure fuel coupling leakage at high temperature, RT, and -65°F
- Results are depicted in UDRI report # WP-TR-2000-2017 dated May 2000 (test activity 09/30/2000)

Current Test Program

- New materials tested for physical properties by METSS Corp. under an SBIR.
- Three new materials downselected as possible material improvement over current o-ring materials.
- Functional Testing desired to compare performance and usage life of new materials to current materials.
  - Utilized concept of previous fuel coupling tests
  - Upgraded the test rig for better control of temperature, fuel flow and leakage measurement.

Upgraded Test Stand Development/capabilities

- Upgraded Test Stand Capabilities
  - All materials subjected to near identical time of fuel exposure and environmental conditions for both high temperature aging and low temperature leakage measurements.
  - Isolate coupling leakage measurement to a give O-ring material and coupling type (variable and fixed) in a single test line
  - Consistent low temperature fuel leakage measurements by use of an environmental chamber
  - Fuel leakage collection and measurement system
  - Thermocouple pickups on manifold test fixture located within environmental chamber (4 ea.) fuel tank and external fuel lines

Upgraded Test Stand Development/capabilities Con’t

- Upgraded Test Stand Capabilities (con’t)
  - Pressure transducer and gauge pressure pickups
  - Provisions for up to sixteen combinations of O-ring materials and couplings
  - Six test specimens for each different O-ring materials of a given size
  - Utilizes –214 and –216 O-ring sizes (fixed/variable couplings)
  - Reservoir for additional fuel capacity during low temperature tests
  - Continuous operation and unmonitored safe operation 24 hours/day
  - Computer data collection and continuous recording of temperatures, pressures, etc.

Test Rig Schematic

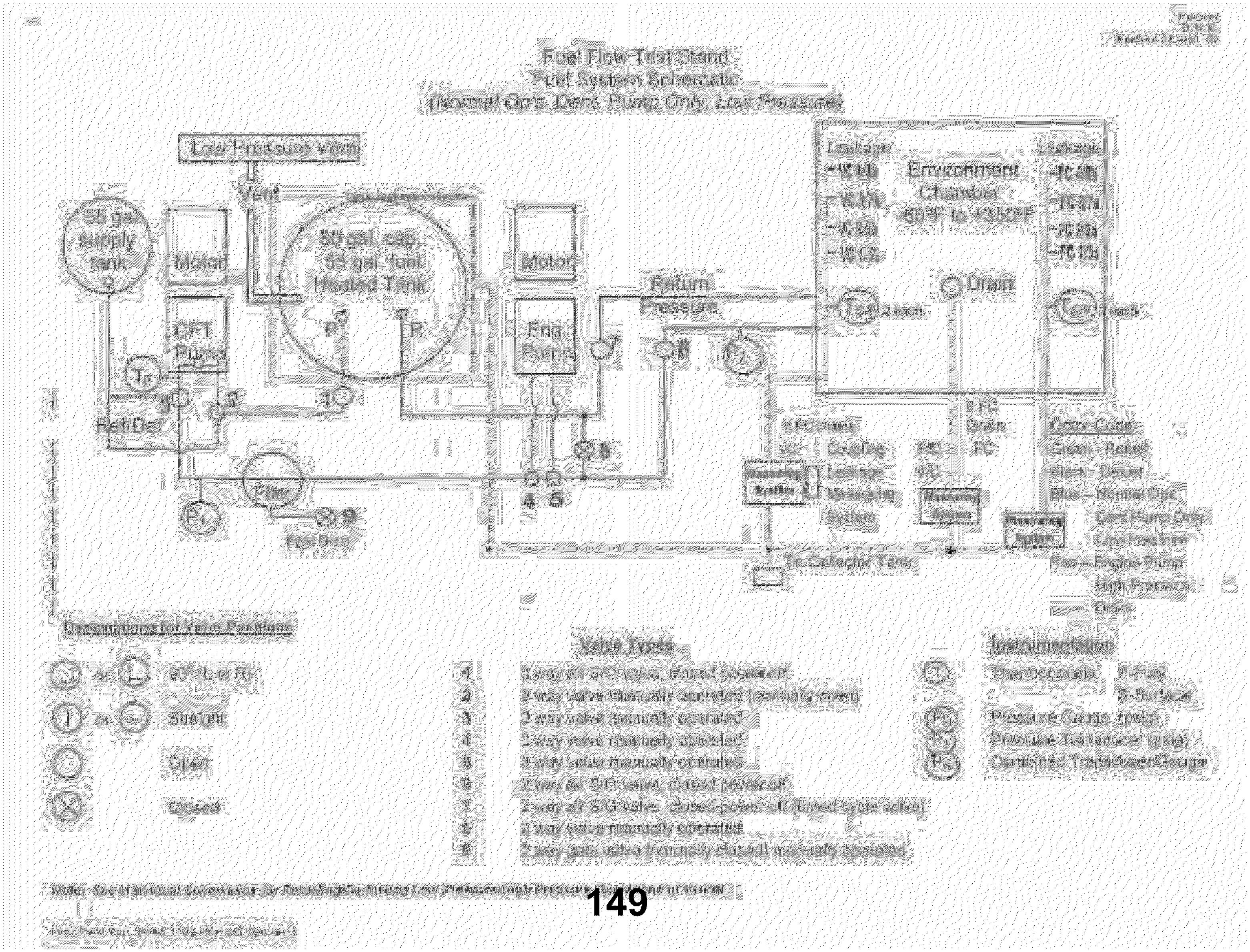
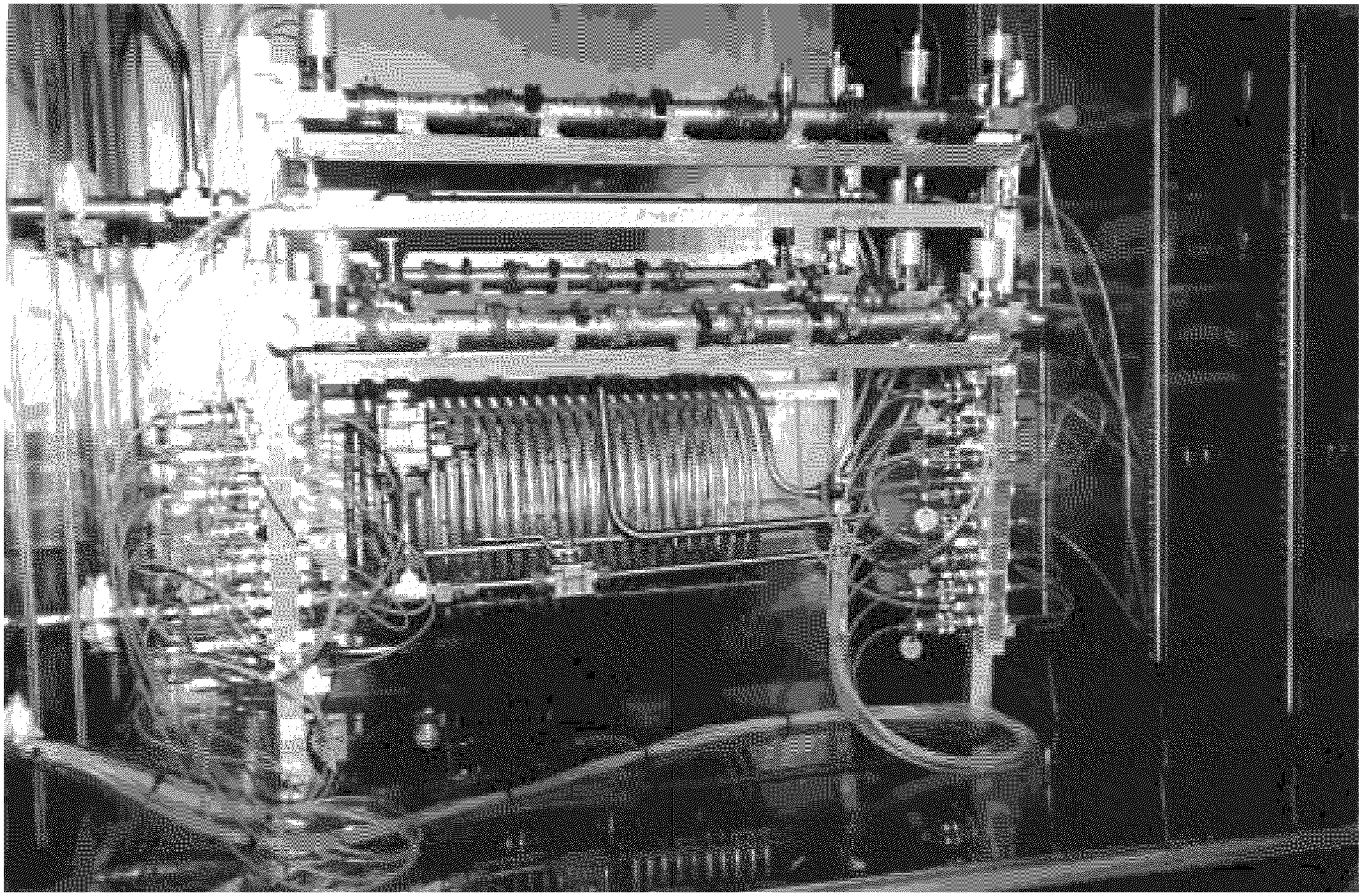


Photo of Fuel Lines with Couplings



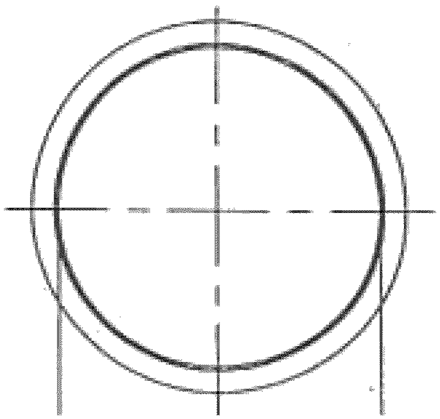
Coupling Test Fixture

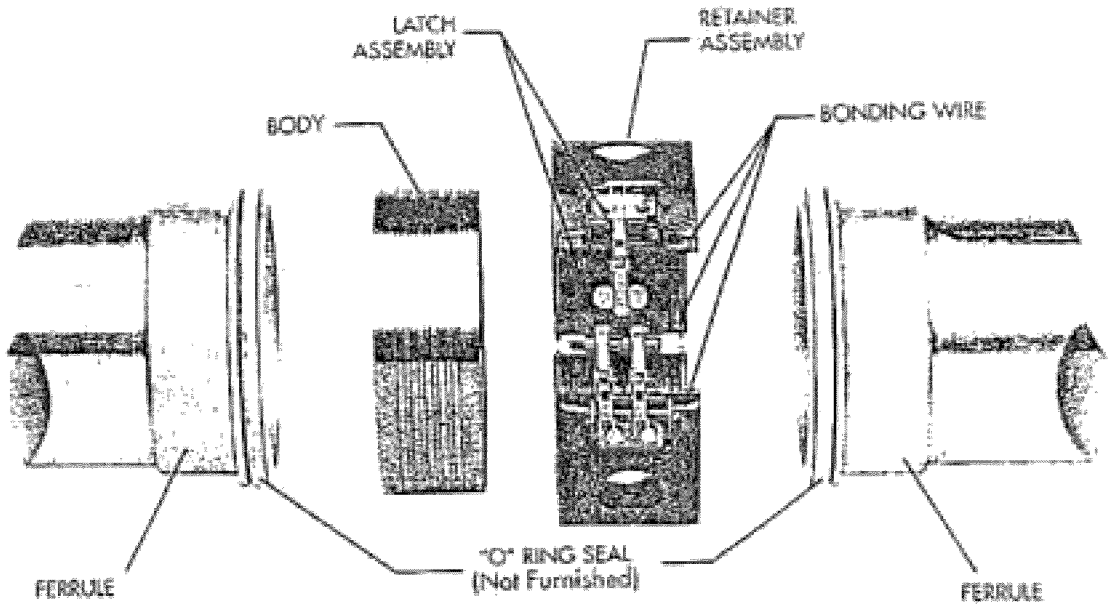
Upper View: Top Row: Fixed Cavity, 6 each row
Bottom Row: Variable Cavity, 6 each row

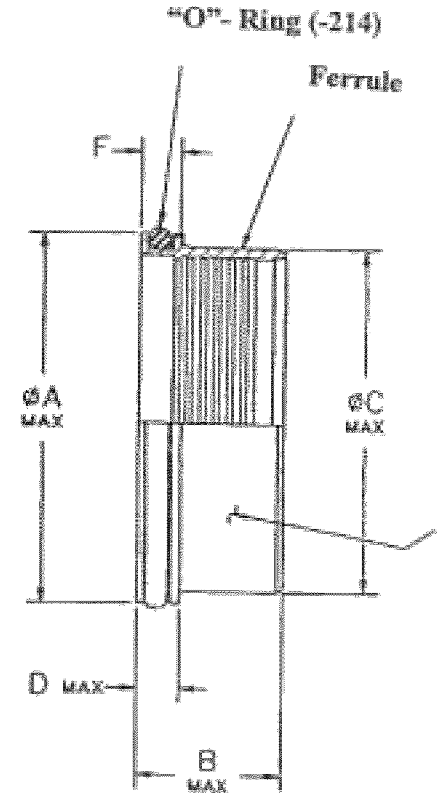
Lower View Center: Heat Exchanger
Left and Right Side: Leakage Measurement Lines

150

Fixed Cavity Coupling



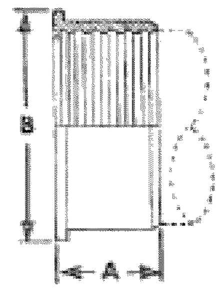


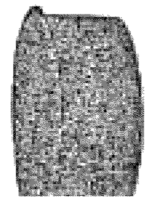


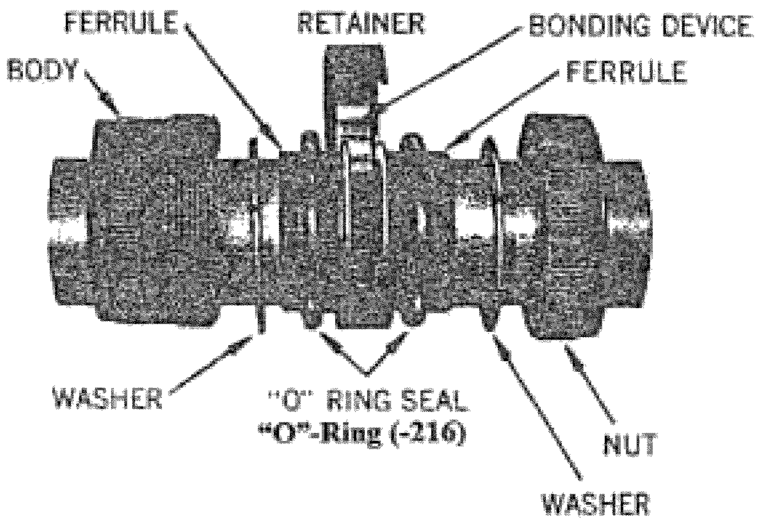
151
Fixed Cavity Coupling

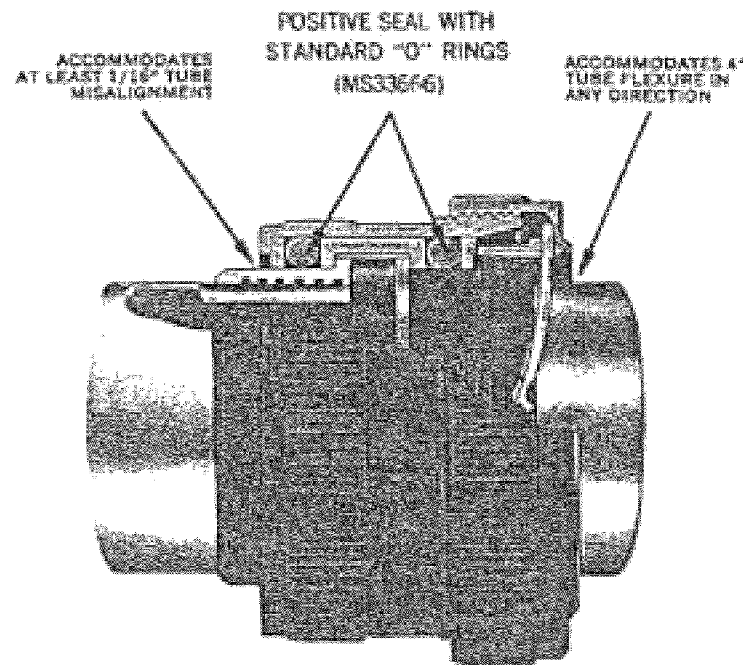
Variable Cavity Coupling

FERRULE (S3052DE)



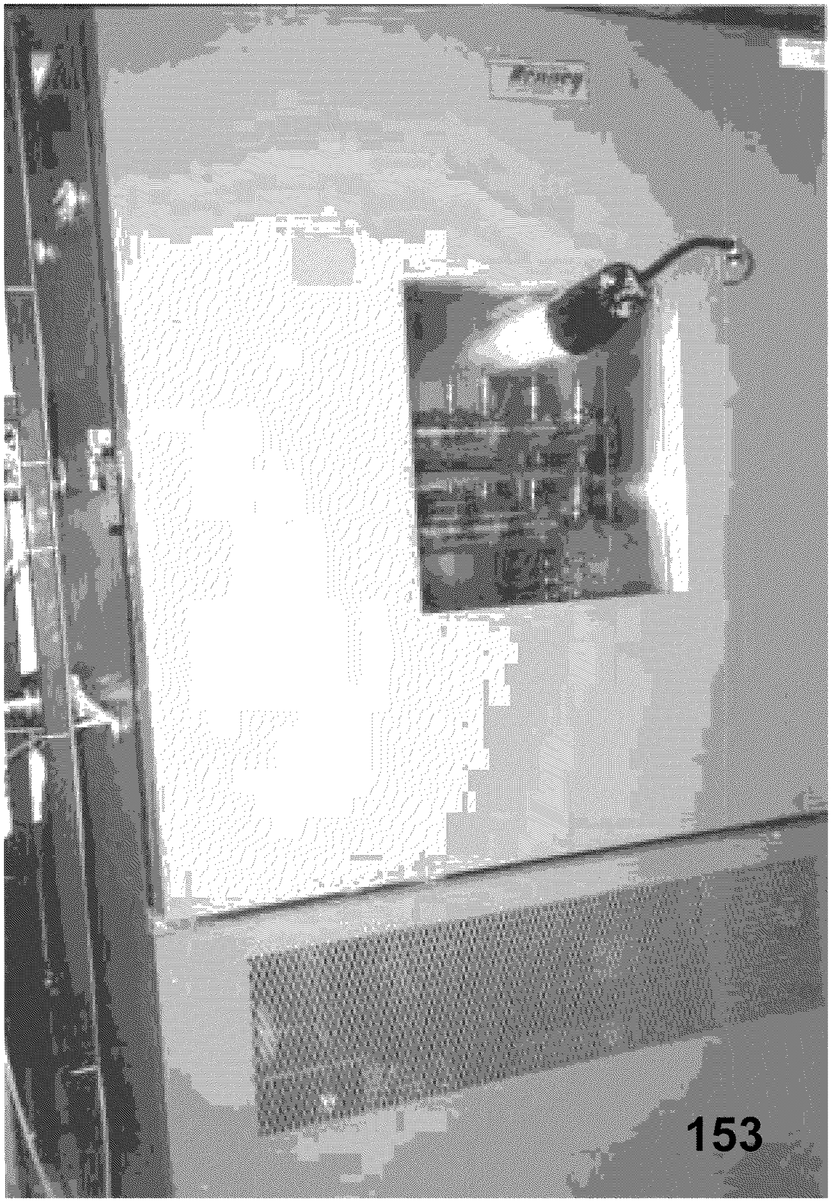






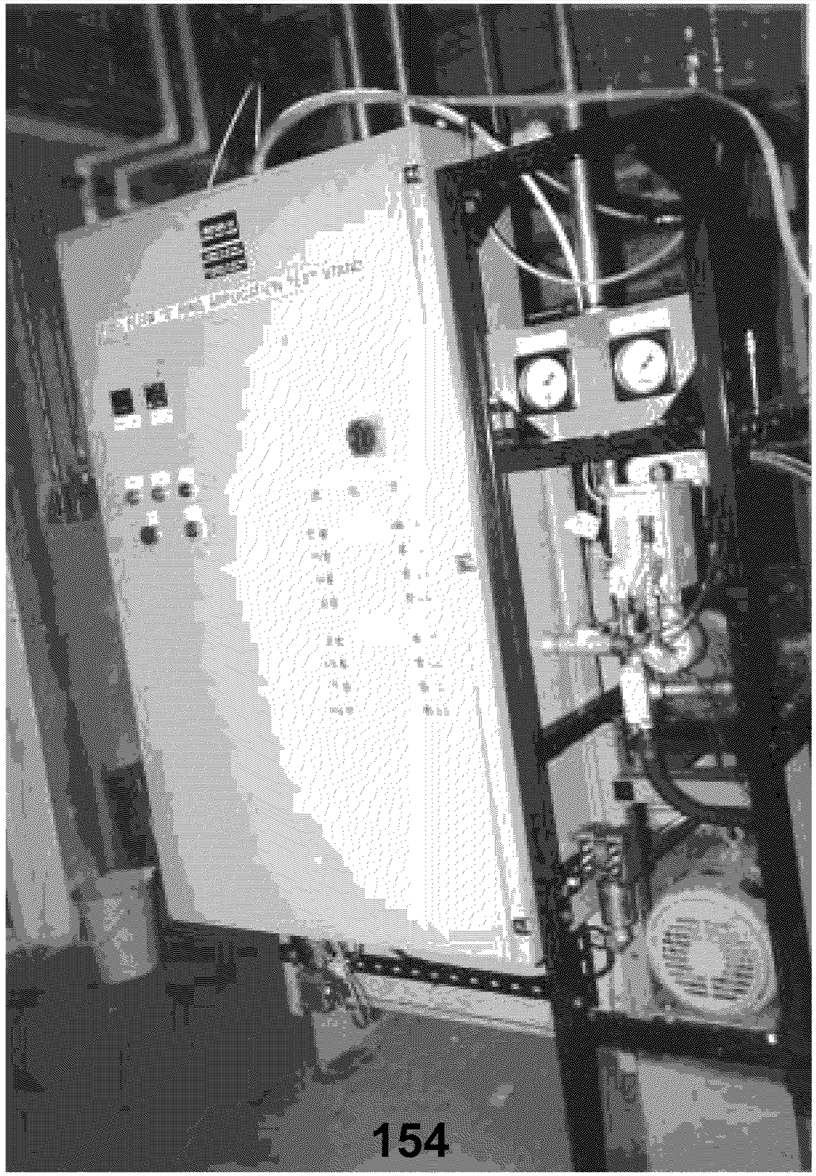
152
Variable Cavity Coupling

Environmental Chamber

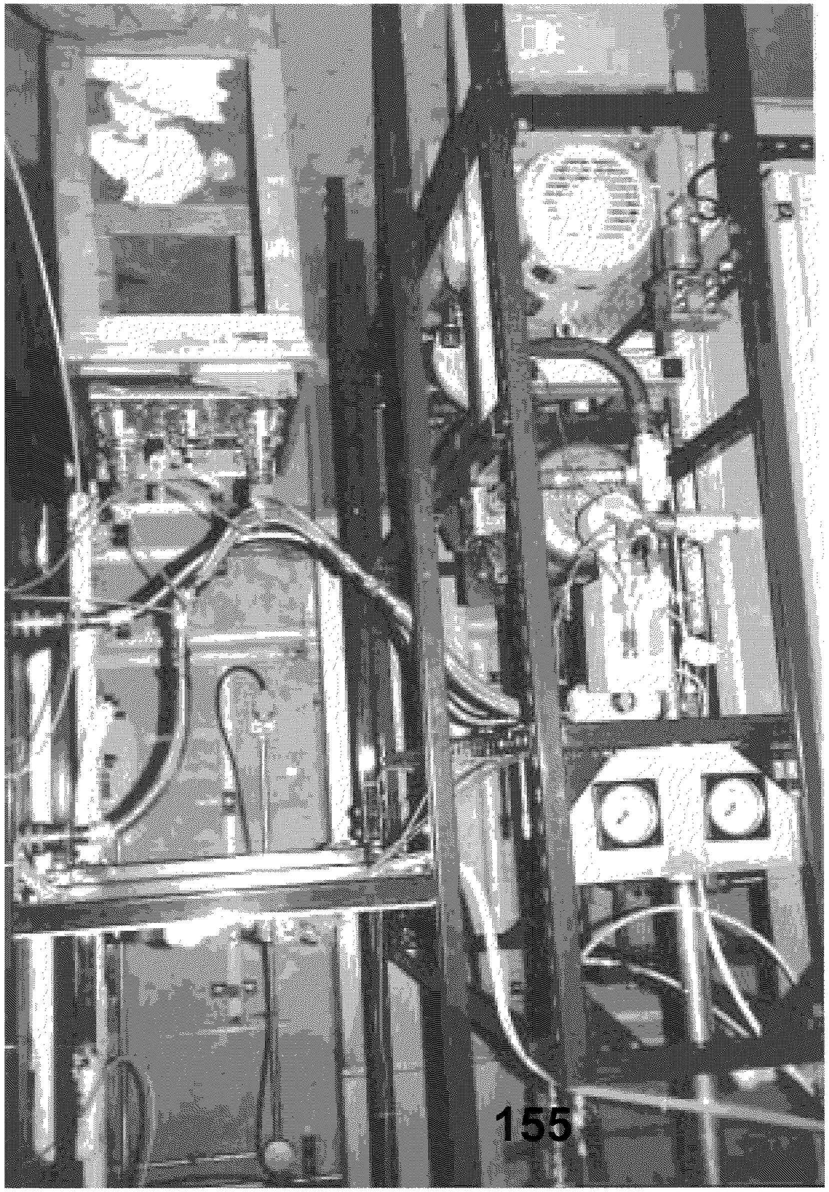


Environmental Chamber

Test Rig Control Center



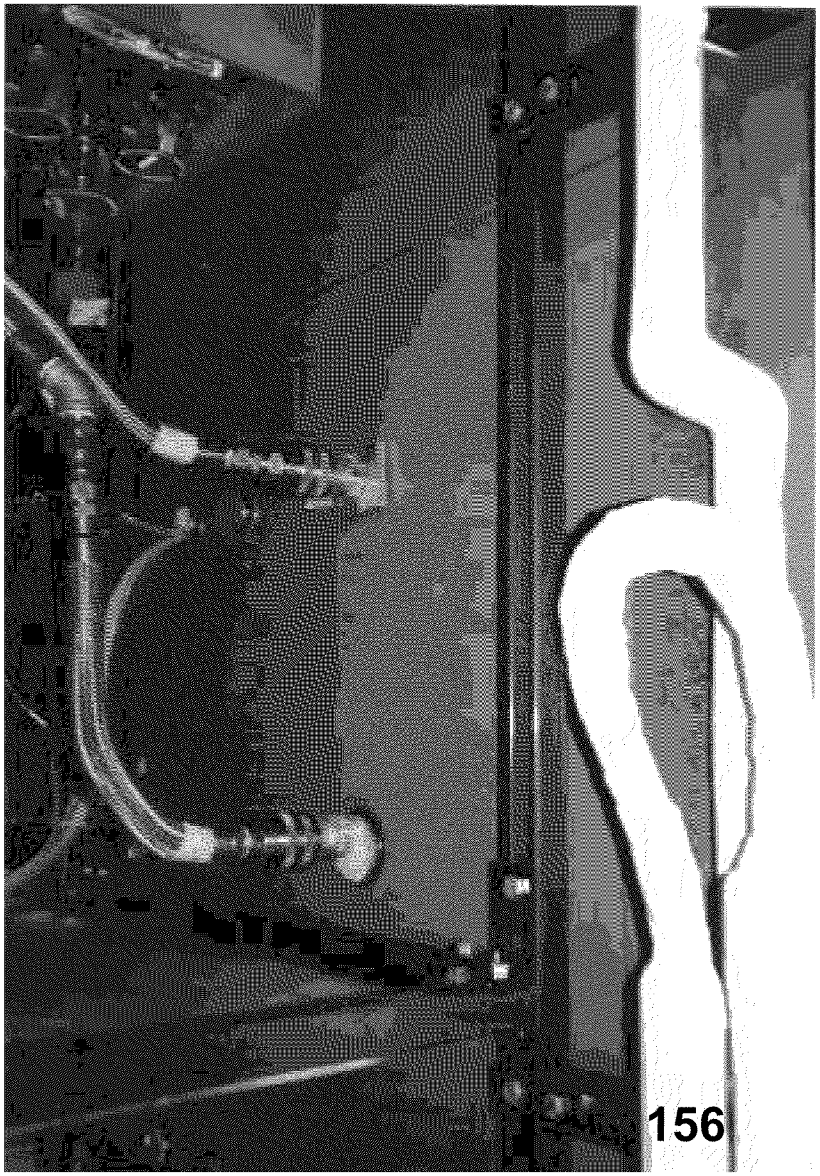
Test Rig Plumbing



System Plumbing Chamber
Fuel In / Out Pump Motors

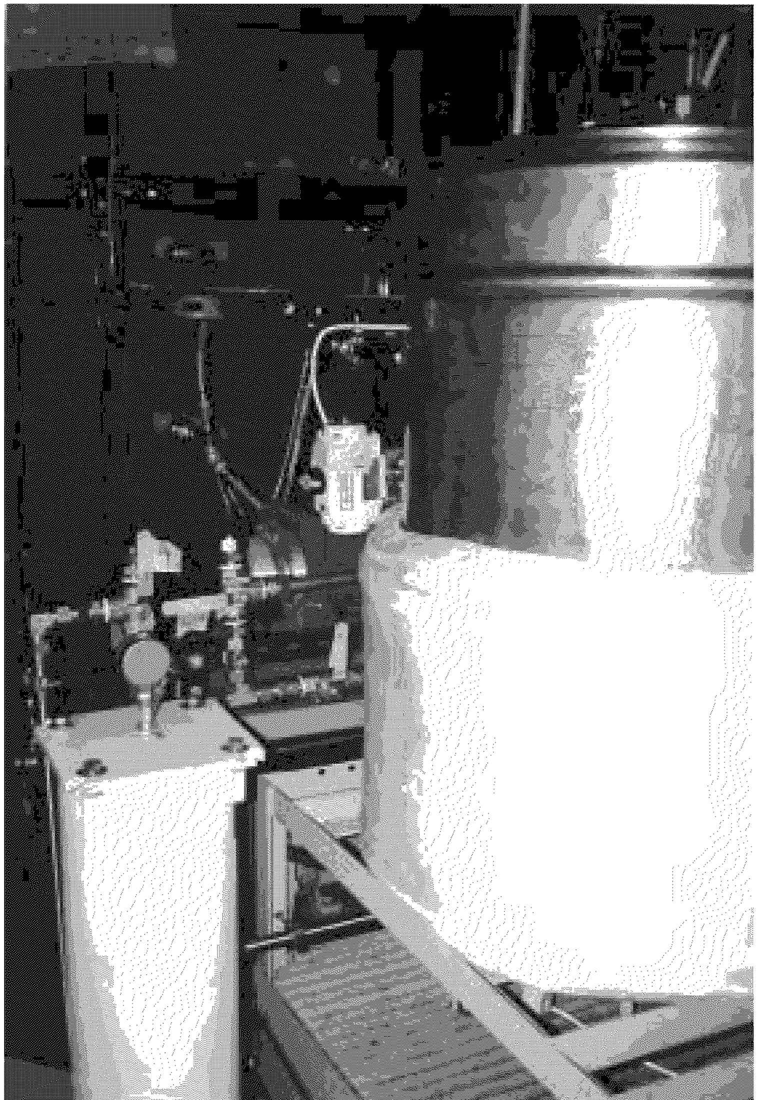
155

Fuel Lines



Environmental Chamber
Fuel In / Out Lines

Fuel Tanks and Filter



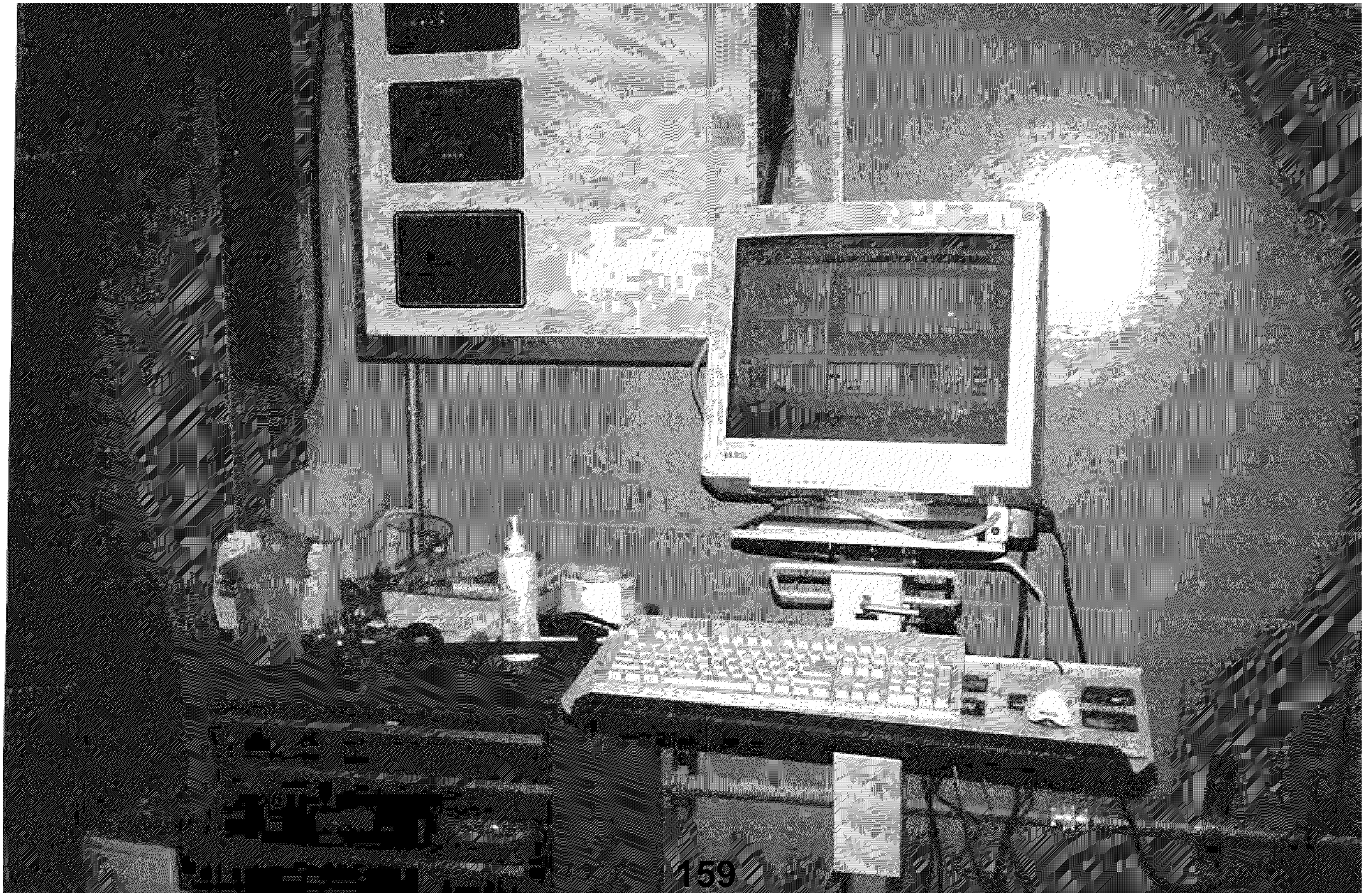
Heated Fuel Tank- Right

Fuel Filter - Left

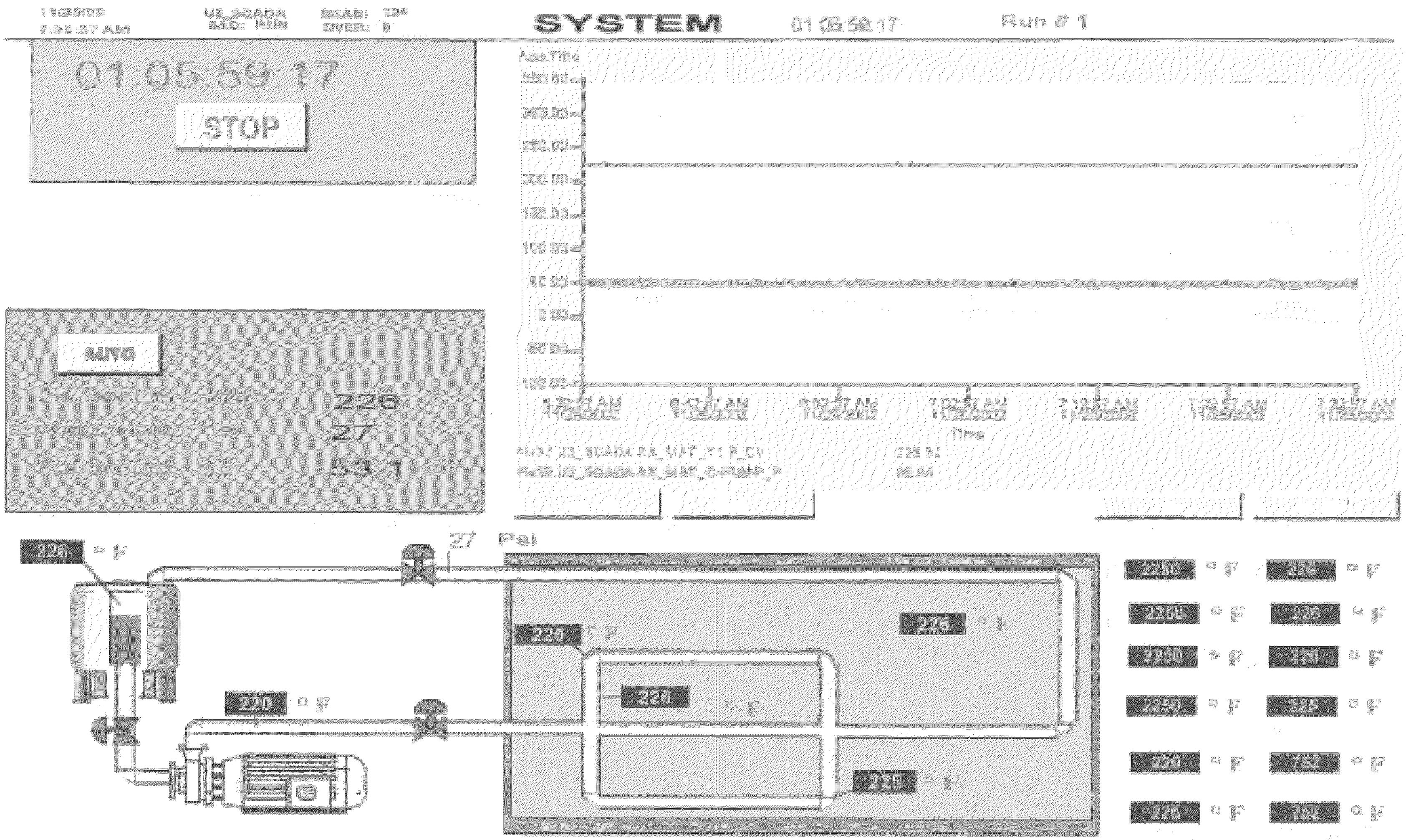
157

Temperature Controller

Computer Monitoring Station



Computer Monitor



160

Data Sheet

Fuel Flow Application Test Stand Data Sheet

Fuel Leakage Symbols & Manufacturer

Leakage = Drops/Second

VC = Variable Cavity
FC = Fixed Cavity
W = Wetting
VSD = Very Slow Drip
SD = Slow Drip
FD = Fast Drip
R = Running
V = No Leak

P = Parker
GTC = Green Tweed

Test Run No.: 1 Aging Temperature: 225 ° F
Type Fuel: JP-8 POSF NO. 02-POSF-4177 (-70ºF Freeze Pt.
Pre-Test Leakage Date: 18 Nov '02 Time: 1600 hrs
Test Initiation Date: 19 Nov '02 Time: 1335 hrs
Test Completion Date: 26 Nov '02 Time: 1030 hrs
Post-Test Leakage Date: 26 Nov '02 Time: 1715 hrs
"O"-Ring Measurement *Pre* Date: 18 Nov '02
"O"-Ring Measurement *Post* Date: 27 Nov '02 Time: 1300 hrs

Coupling Leakage Results Pre / Aging / Post Test
Leakage Temperature T_1 Pre- -65 ºF; T_1 Post - -65 ºF

"O"-Ring Material Type	Line No.	Coupling Number												Fuel Aging Hours		
		1 (VC)		2(VC)		3 (VC)		4 (FC)		5 (FC)		6 (FC)		Total	325ºF	Δ
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post			
MIL-P-5315 Nitrile	1	?	?	VSD **	?	?	SD	?	?	?	?	?	?	213	162	51
AMS-7271 Nitrile	2	?	?	?	?	?	?	?	?	?	?	?	?	213	162	51
MIL-R-25988 Fluorosilicone	3	?	?	?	?	?	?	?	?	?	?	?	?	213	162	51
MIL-R-25988 Fluorosilicone	4	?	?	?	?	?	?	?	?	?	?	?	?	213	162	51
MIL-R- 25988 Fluorosilicon	5	?	?	?	?	?	?	?	?	?	?	?	?	213	162	51
MIL-R-25988 Fluorosilicon	6	?	?	?	?	?	?	?	?	?	?	?	?	213	162	51
AMS-7271	7	?	?	?	?	?	?	?	?	?	?	?	?	213	162	51
MIL-P-5315 Nitrile	8	R**	SD	?	?	?	?	?	?	?	?	?	?	213	162	51

Pressure P_1 (60) PSIG Pressure P_2 (60) PSIG Δ Time includes ambient temp. time, and transition time from ambient to low temp. and ambient to high temp.

* Premature Shutdown Due to Water Main Break 3 hrs & 5 Minutes
** Tightened at Room Temperature Before Aging

Δ Time includes ambient low temperature transition leakage test (ambient to high)

Test Materials and Fuel Properties Con't

Test Run #1 (7 days @ 225°F, JP-8)

Line #	*I.D. No.*	*Specification #*	*Material*	*Type Coupling / O-Ring Size*
1.	I.G.3	MIL-P-5315	Nitrile	1-3 VC-216 / 4-6FC-214
2.	I.G.4	AMS-7271	Nitrile	1-3 VC-216 / 4-6FC-214
3.	I.G.5/II.G.2	MIL-R-25988	Fluorosilicone	1-3 VC-216 / 4-6FC-214
4.	II.G.7	MIL-R-25988	Fluorosilicone	1-3 VC-216 / 4-6FC-214
5.	II.G.7	MIL-R-25988	Fluorosilicone	1-3 VC-216 / 4-6FC-214
6.	I.G.5/II.G.2	MIL-R-25988	Fluorosilicone	1-3 VC-216 / 4-6FC-214
7.	I.G.4	AMS-7271	Nitrile	1-3 VC-216 / 4-6FC-214
8.	I.G.3	MIL-P-5315	Nitrile	1-3 VC-216 / 4-6FC-214

Test Materials and Fuel Properties Con't

Test Run #2 (7 days @ 225ºF, JP-8 + 100)

Line #	*I.D. No.*	*Specification #*	*Material*	*Type Coupling / O-Ring Size*
1.	I.G.3	MIL-P-5315	Nitrile	1-6 Fixed Cavity/-214
2.	I.G.4	AMS-7271	Nitrile	1-6 Fixed Cavity/-214
3.	I.G.5/II.G.2	MIL-R-25988	Fluorosilicone	1-6 Fixed Cavity/-214
4.	II.G.7	MIL-R-25988	Fluorosilicone	1-6 Fixed Cavity/-214
5.	II.G.7	MIL-R-25988	Fluorosilicone	1-6 Variable Cavity/-216
6.	I.G.5/II.G.2	MIL-R-25988	Fluorosilicone	1-6 Variable Cavity/-216
7.	I.G.4	AMS-7271	Nitrile	1-6 Variable Cavity/-216
8.	I.G.3	MIL-P-5315	Nitrile	1-6 Variable Cavity/-216

Test Materials and Fuel Properties Con't

Test Run #3 (7 days @ 325°F, JP-8)

Line #	*I.D. No.*	*Specification #*	*Material*	*Type Coupling / O-Ring Size*
1.	II.G.2	MIL-R-25988	Fluorosilicone	1-3 VC -216 / 4-6 FC –214
2.	II.G.7	MIL-R-25988	Fluorosilicone	1-3 VC -216 / 4-6 FC –214
3.	II.G.15	MIL-R-25988	Fluorosilicone/Teflon	1-3 VC -216 / 4-6 FC –214
4.	II.G.9	MIL-R-83248	Fluorocarbon	1-3 VC -216 / 4-6 FC –214
5.	II.G.3	MIL-R-83485	Fluorocarbon/GLT	1-3 VC -216 / 4-6 FC –214
6.	II.G.6	MIL-R-83485	Fluorocarbon/GLT	1-3 VC -216 / 4-6 FC –214
7.	II.G.12	MIL-R-83485	Fluorocarbon/GLT	1-3 VC -216 / 4-6 FC –214
8.	II.G.14	MIL-R-25988	Fluorosilicone/Teflon	1-3 VC -216 / 4-6 FC –214

Test Materials and Fuel Properties Con't

Test Run #4 (To failure @ 325ºF, JP-8)

Line #	*I.D. No.*	*Specification #*	*Material*	*Type Coupling / O-Ring Size*
1. (1-3)	New #1		New	VC-216
2. (1-3)	II.G.12	MIL-R-83485	Fluorocarbon (GLT)	VC-216
3. (1-3)	New #2		New	VC-216
4. (1-3)	New #3		New	VC-216
5. (1-3)	II.G.12	MIL-R-83485	Fluorocarbon (GLT)	FC-214
6. (1-3)			No Line	
7. (1-3)	New #2		New	FC-214
8. (1-3)	New #3		New	FC-214
1. (4-6)	II.G.2	MIL-R-25988	Fluorosilicone	FC / -214
2. (4-6)	II.G.6	MIL-R-83485	Fluorocarbon (GLT)	FC / -214
3. (4-6)	II.G.3	MIL-R-83485	Fluorocarbon (GLT)	FC -214
4. (4-6)	II.G.7	MIL-R-25988	Fluorosilicone	FC / -214
5. (4-6)	II.G.6	MIL-R-83485	Fluorocarbon (GLT)	VC / -216
6. (4-6)			No Line	
7. (4-6)	II.G.2	MIL-R-25988	Fluorosilicone	VC / -216
8. (4-6)	II.G.7	MIL-R-25988	Fluorosilicone	VC / -216

Test Materials and Fuel Properties Con't

Fuel

Types

- JP-8 (includes standard additives) (02 POSF 4177)
- JP-8 + 100 Betz TSA

Properties

Total Acid No.	0.004
Aromatics Volume %	15.3
Olefins Volume %	0.9
Mercaptan Sulfur % Mass	0.001
Total Sulfur % Mass	0.014
Flash Point	52ºC
Freeze Point	-57ºC / -70.6ºF
Viscosity @ 20ºC s ST	2.7
Existing Gum, mg/100ml	1.8
Conductivity pS/m	157

Test Procedures and Test Values

- Time of Material Aging in Flowing Fuel at Temperature
  - Test sets No.'s 1, 2, 3 ~ 7 days
  - Test set No. 4 until Failure (~ 7 day leakage assessment at low temperature)

- Fuel Change-out
  - Between each test set i.e.: #1, #2, #3
  - Once every two weeks (test to failure)

Test Procedures and Test Values Con't

- Temperature Leakage Measurements (Pre-Aging Tests and 7 Day Intervals)
  - Aging temperature (i.e.: 225 and 325ºF) throughout test
  - Ambient temperature (approx. 72ºF)
  - Low temperature test 32, 0, -10, -40, -65ºF @ 7 day intervals
- Pressure Leakage Measurements
  - Flowing pressure (approx 15 to 30 psig)
  - 60 psig and 0 psig
- Observations
  - Leakage Measurements
  - Running leak
  - Drops/second (stop watch)

Coupling/O-Ring Failure Criteria Test Result Eval Criteria

O-ring material failure was established based on fuel coupling leakage criteria noted below. Monitoring of fuel leakage consisted of Pre- and Post 7 day aging at temperature and post low temperature measurements and daily observations.

Failure Criteria

– Running leakage at any test temperature

– Any leakage down to 0°F

– When two or more couplings of a given material are leaking at temperatures below 0°F unless the pre-test leakage is equal to or greater than the post-test leakage. I.e.: fluorocarbons

Conclusions, Preliminary (Test Incomplete)

Existing O-Ring Materials / Results:

- Fluorosilicone #1 failed after the second 7-day week of testing in one variable cavity coupling running leak (Line #7)
- Fluorosilicone #1 material in the fixed cavity coupling is starting to leak during the 6th and 7th week at -40ºF and 65ºF of testing. No running leak
- Fluorosilicone #2 material started leaking in a variable cavity coupling at 0ºF in the sixth week and a running leak in one coupling at room temperature through -65ºF the 7th week, thereby a failure
- Fluorosilicone #2 material in the fixed coupling is starting to leak during the 6th and 7th week at -65ºF of testing. No running leaks.
- GLT fluorocarbon #1 material did not leak in the fixed cavity coupling after the 7th 4 day/week test results and only small amount of leakage in the variable cavity coupling at -65ºF throughout the test period of 7 weeks. Some initial new material leakage (no aging) occurred in both the fixed cavity and variable cavity couplings at -40ºF and -65ºF
- GLT fluorocarbon #2 material exhibited an increased leakage after 7 weeks of testing at -40ºF and -65ºF, but no running leak in either the variable coupling or the fixed cavity coupling
- GLT fluorocarbon #3 material did not leak in a fixed cavity coupling after the 3rd week, and no leakage after the 7th (4 day) week. This material was not installed in a variable cavity coupling

Conclusions, Preliminary (Test Incomplete)

<u>New O-Ring Materials / Results:</u>

- **New Material #1 no leaks to date.**
- **New Material #2 failed in the variable cavity couplings at week 2.**
- **New material #3 no leaks to date.**

Test Results (Coupling Leakage)

- 325ºF Leakage Measurements Results after Each 7 Days Temperature Aging Period in JP-8 Fuel

	Material Failure
– First 7-day period	No Failure
– Second 7-day period	New #2 Variable Cavity
	25988 Variable Cavity
– Third 7-day period	No Failure
– Fourth 7-day period	No Failure
– Fifth 7-day period	No Failure
– Sixth 7-day period	No Failure
– Seventh 4-day period*	25988 Variable Cavity
	Coupling (Running Leak at Room Temp
	through -65ºF

172 Test was terminated due to environmental chamber availability.

General Conclusions, Preliminary

Test Run #4

- No couplings leaked at the aging temperature of 325°F
- Only one coupling, Fluorosilicone, leaked (variable cavity) after the 7^{th} week (4 days partial week) at room temperature
- All other coupling leakages occurred at temperatures below room temperature during the low temperature test cycle
- Variable cavity couplings typically leaked more frequently than the fixed cavity couplings with a given O-ring material.

Recommendations, Preliminary (Testing Incomplete)

- Testing at 325°F aging temperature be resumed for Test Run #4 as soon as the environmental chamber becomes available. All test coupling materials be run until failure criteria are met

- All materials of Test Run #3 and #4 be run at 325°F in JP-8 + 100 Betz fuel additive, to failure

- All materials of Test Run #1 and new materials be run at 225°F in JP-8 fuel and JP-8 + 100 Betz fuel additive to failure.

PAX NAS HYDRAULICS LIAISON REPORT

WPAFB Fluids Workshop, June 15, 2004

Jeff Gribble

Aging Aircraft Program

POC's

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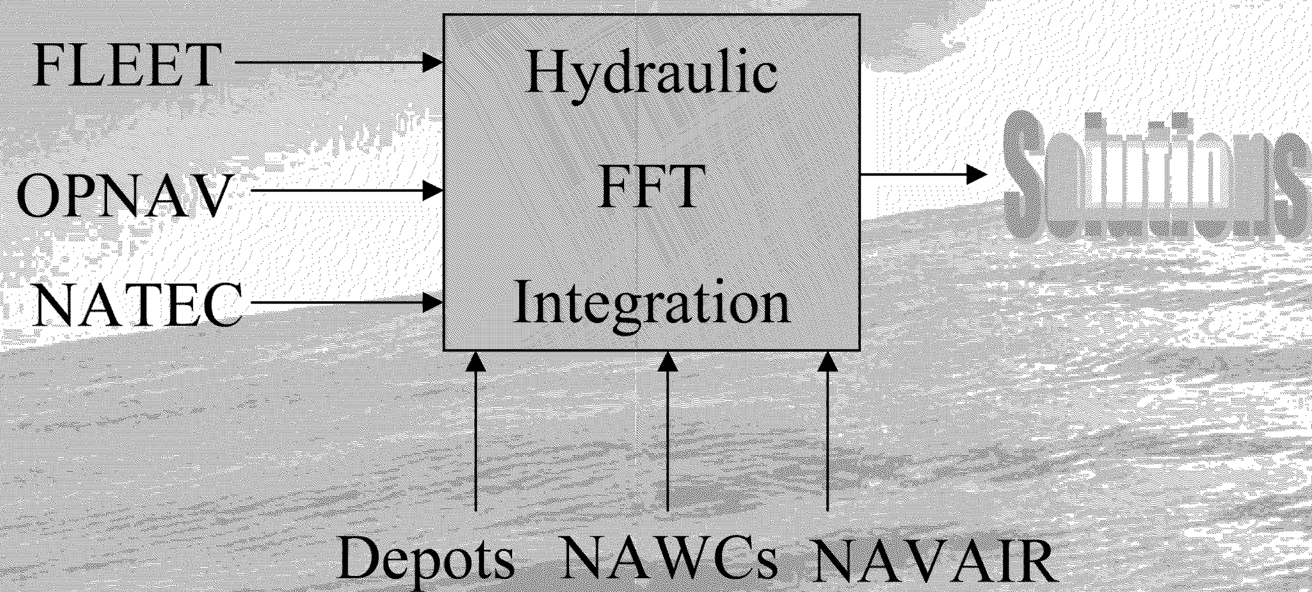
NAVAIR

Aging Aircraft Program

Hydraulic Fleet Focus Inputs



Any Inputs From Industry On Projects Are Welcome

Aging Aircraft Program

Current Project List

#1 - MIL-C-85052 Revision (UV and Ozone Effects on Hydraulic Tubing Clamp Cushions)

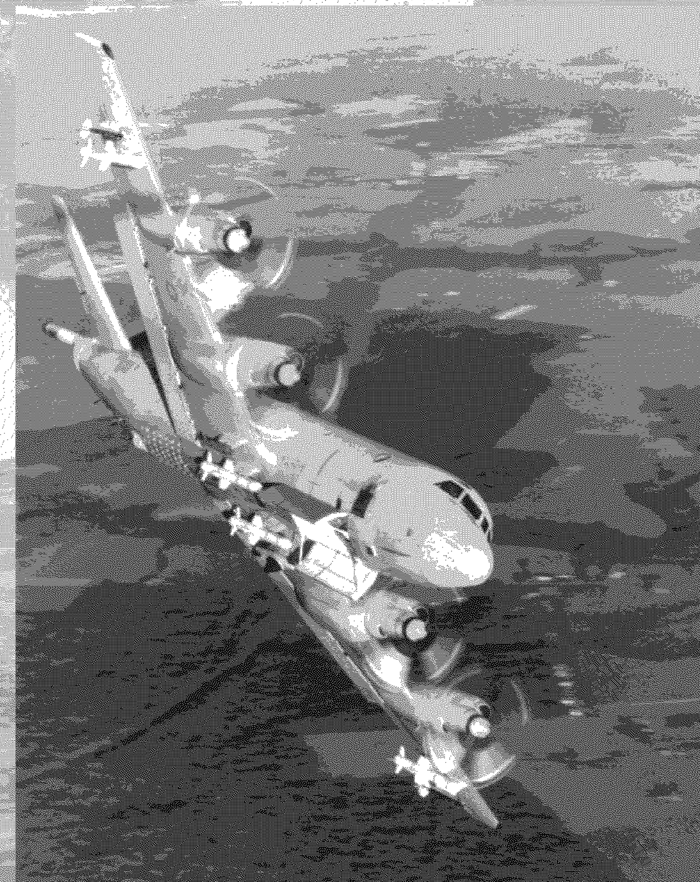
#2 - NAVAIR 01-1A-20 Hydraulic Tube Repair Manual Amendment (Specify Wall Thickness of CRES Tubes as Replacement to Titanium)

#3 – Quick Disconnect/Manifold Alignment (on H-60 Actuators)

#4 – HVOF Rod Coating Developmental Testing

#5 – Superfinish Rod Coating (Research Coating for Hydraulic App.)

#6 – H-60 Primary/Boost/Tail Rotor Servo Seal Upgrade



Any Inputs From Industry On Projects Are Welcome

Project #1: MIL-C-85052 Update & Test

Issue:
Rubber cushions on hydraulic tube clamps have been cracking in the fleet.

Solution:
PAX will revise the specification based on analysis of test results. Lakehurst will publish the spec. PAX will recertify the present QPL vendors.

Costs:
\$15k (PAX) + \$10k (LH) = \$25k Total

Deliverables:
Changes to specification and requalification of QPL vendors will provide the fleet with more reliable clamp cushions.

NAVAIR

Project #2: NAVAIR 01-1A-20 Update

Issue:

Fleet is replacing titanium tubes with CRES tubes during repair without guidance from the –20 Hydraulic Tube Repair Manual.

Solution:

NI/PAX will create a chart illustrating acceptable replacement tubes per size and thickness based on researchable data to modify the -20 manual. Cherry Point finalize changes and publish manual.

Costs:

\$5k (NI) + \$5k (CP) = \$10k Total

Deliverables:

The -20 manual will specify appropriate Ti tube replacement of CRES tubes.

Project #3: QD/Manifold Alignment Evaluation & Test

Issue:

QD's for connecting H-60 actuators to the hydraulic system have been identified as degrader components. DOD spent $1.3 million in 2002 alone for replacement spares.

Solution:

FY 2004 funding utilized to initiate effort. Project completed in FY 2005. Cherry Point plans to use FST funds to investigate manifold alignment on a/c in Aug/Sept 2004.

Costs:

$15k (PAX) + $5k (CP) = $20k Total

Deliverables:

CP and PAX investigate failed fittings removed from A/C. PAX perform preliminary tests on QDs to determined deficiencies. CP/PAX work with OEM for possible fixes.

Project #4: HVOF Rod Coating Test

Issue:
Current chrome plating on actuator pistons are an environmental hazard.

Solution:
JAX prepare test specimens. PAX perform developmental tests on various coatings and surface finishes.

Costs:
$15k (JAX) = $15k Total

Deliverables:
Test results will lead to HVOF coatings on actuator pistons, which outperform chrome plating and provide environmental benefits.

Project #5: Superfinish Rod Coating Research

Issue:
Chrome plating replacements are need for aging a/c.

Solution:
PAX research benefits of Superfinish to determine if it is worthy of future developmental testing.

Costs:
$5k Total (JAX)

Deliverables:
Research will determine if Superfinish is a possible solution to chrome plating for hydraulic application and should be evaluated through further testing.

Project #6: H-60 Seal Improvement Upgrade

Issue:

Seal leakage is most common removal cause for H-60 boost, tail rotor, primary servo actuators. Parker and Sikorsky require lengthy, costly testing.

Solution:

Coordinate with Parker and Sikorsky meet minimum system requirements at lowest cost.

Costs:

Remaining FY-04 funding--$15k (PAX) + $15k (CP) + $60k (Parker/SAC) = $90k Total

Deliverables:

Qualified actuators with improved seals and HVOF rod coating for Navy, Coast Guard, and Army.

Lower Priority Projects

Several projects have been identified and listed on the Rack Stack list that cannot be worked in Fiscal Year 2004 for several reasons:

- Lack of manpower required to work the projects this year.
- Projects may not have a fast turnaround time for deliverables.
- Projects simply may not be a big degrader issue to the fleet.

Lower priority projects on the Rack-Stack include:

- E2/C2 Improved Dynamic Seals Used on Advanced Hawkeye
- Metal Filters
- MIL-F-8815 Evaluaion
- Rynglok Tools and Fittings to Replace Permaswage
- Airborne Air Removal Device

POC's

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V-22 Osprey Highlights

Flight Test Aircraft

- 2 EMD Configuration Aircraft at EAFB
- 8 at PAX NAS (2 EMD, 4 LRIP, 2 Block-A DT)
- A/C 24 Completed Natural Icing Testing in Nova Scotia
- A/C 21 Performing Aerial Retractable Re-Fuel Probe Flight Testing

VMX-22 MCAS Training Squadron New River, NC

- 6 Block-A Configuration Aircraft---Over 800 Hours

Program Has Over 2,000 Flight Hours Since Return To Flight

Program Schedule

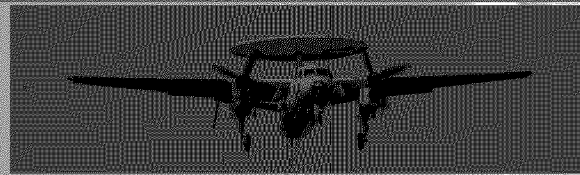
- 12 More A/C to New River in 2005
- OTIIF Initial Operation Eval. Started 05/18/2004
- OPEVAL Winter 2005 and Full Rate Production MS Decision Fall 2005

Hydraulic System

- Individual Components vs. System Integration Are Source of Challenges

NAVAIR

E-2C Advanced Hawkeye



Raeanne Makowski
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Program Highlights

Increased Capabilities of Avionics Equipment → Weight Savings

Hydraulic System Changes

- Some 3000psi Al and Steel A/N Flared Tubing → Ti Beam Seal
- Filter Housings and Quick Disconnects → Lighter Weight
- Flight Control Actuators → Spring Energized Seals and HVOF
- Elevator actuator Al body redesign → Lighter Weight

Milestone B by End Of 2004

SD&D Aircraft by 2005

POC Jeff Gribble

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Highlights

H-60

- H-60S Anti-Mine Countermeasures Winch Hydraulic Manifold Qual Testing
    - Proof and Endurance Testing (complete)
    - Impulse Testing (currently)
    - Burst Testing (after completion of impulse)
- H-60R Utility Hydraulic System Pressure Tests
    - Evaluation of Integration with Airborne Low Frequency Sonar (ALFS) Reeling System ~ July 2004.
- Primary and Tail Rotor Servo E.I. of Seal Degradation ~ Aug 04

Other A/C Platforms

<u>H-1 Upgrades (Y/Z)</u> **POC Ed Ryan** Edwin.Ryan@Navy.Mil (301) 342-8507

- Hydraulic System Redesign Complete
  - Hyd Power Increased (8 to 15 GPM)
  - 3 Independent Systems Reduced to 2
  - Thermal Management Issue Solved (Heat EX and Air Ducting)
- UH-1Y and AH-1Z Flight Testing at PAX NAS
  - 3 AH-1Z and 2 UH-1Y (EMD Config)
- Program Nearing End of Flight Testing and Tech Eval
- OPEVAL Scheduled to Begin Early 2005 on 4 EMD A/C

Other A/C Platforms

POC's James Magno & Jeff Gribble

V-XX Presidential Helicopter
Test Requirements Document being Drafted.
Source Selection Process will be Redone.

H-53X (USMC Heavy Lift Replacement)
Aircraft Specification Being Developed

Joint Unmanned Combat Air System (J-UCAS)
- USAF, USN and Defense Advanced Research Projects Agency
- 3 Aircraft Configurations (X-45C, X-45C/N, & X-47B)

Joint Strike Fighter F-35 (JSF)

POC Ed Ryan
Edwin.Ryan@Navy.Mil (301) 342-8507

Program Highlights

Completing Air Vehicle level CDR’s

Weight Reduction Continues To Be the Primary Design Focus

Hydraulics System Configuration is Complete

- Demand Vs. Generation Continued Challenge
- System Utilizes Existing 4000psi Technology

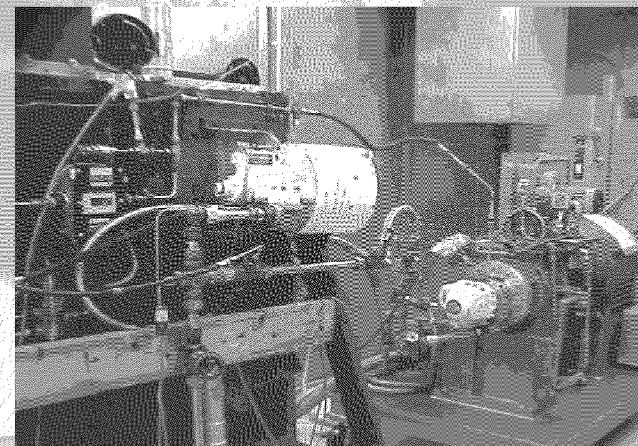
EHA’s---Most Advanced Technology Is Largest Challenge

NAVAIR

PAX NAS

Hydraulic Systems

Test/Evaluation Facility



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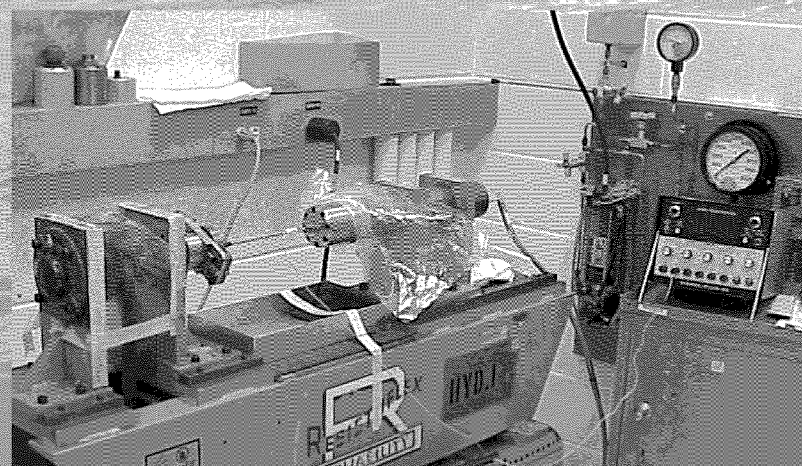
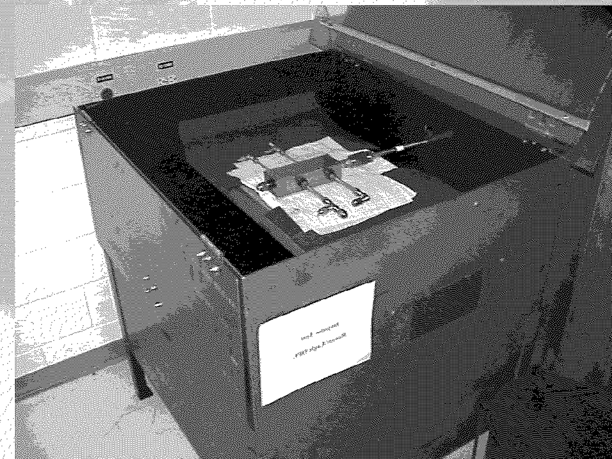


Lab Test/Evaluation Projects

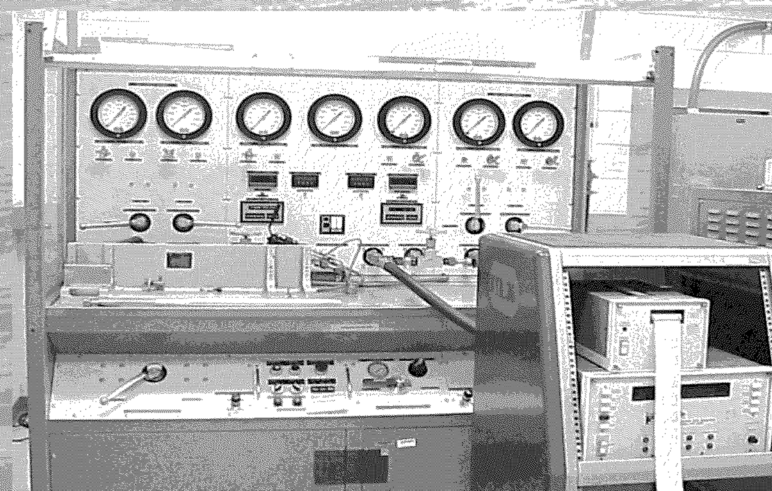


V-22 Damage Limit Impulse Testing

Metal Filter Testing To Verify per MIL-F-8815 (2 Prototypes)

F/A-18 Spring Energized PTFE Seals

- High/Low Temp Unloaded
- Cycling Delta-Qual
- Stabilator Actuator Complete
- Trailing Edge Flap Actuator Next

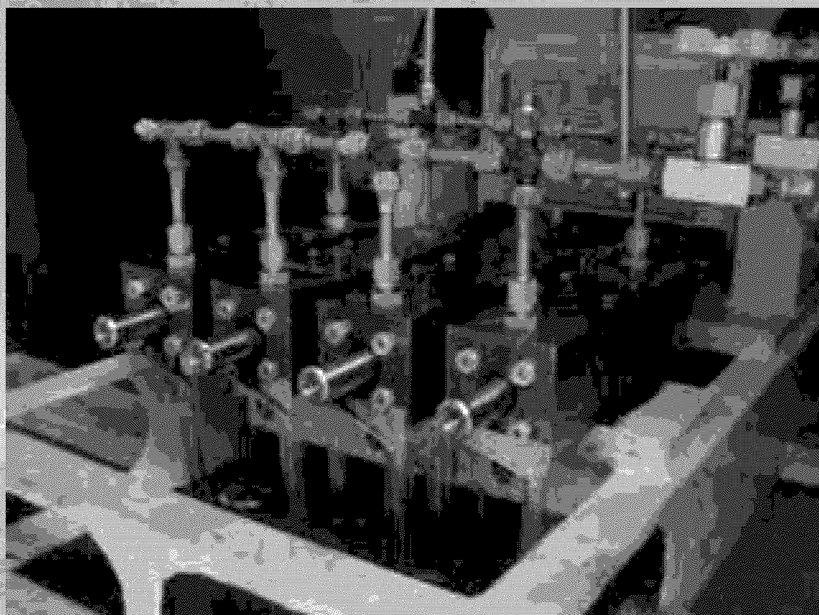


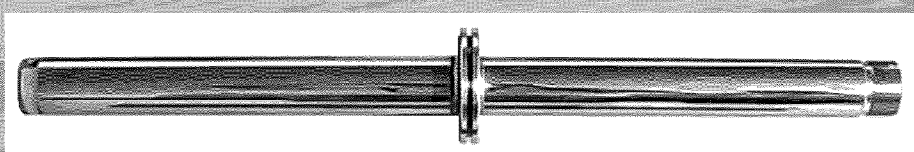
EI's on T-2 Flight Control Actuators

Misc. Qualified Product Testing

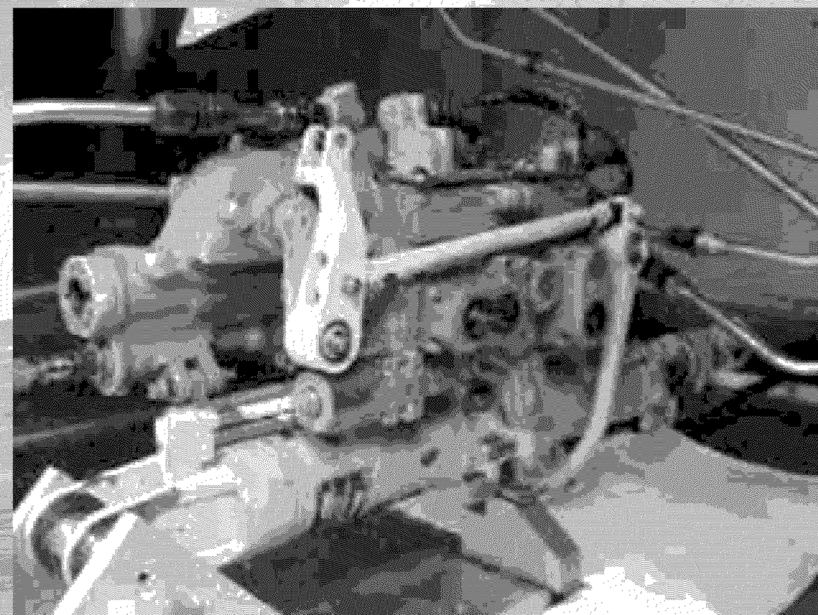
Lab Test/Evaluation Projects (Contd)

Rod/Seal Endurance Test Rig
(4 Rods and 32 Installed Seals)

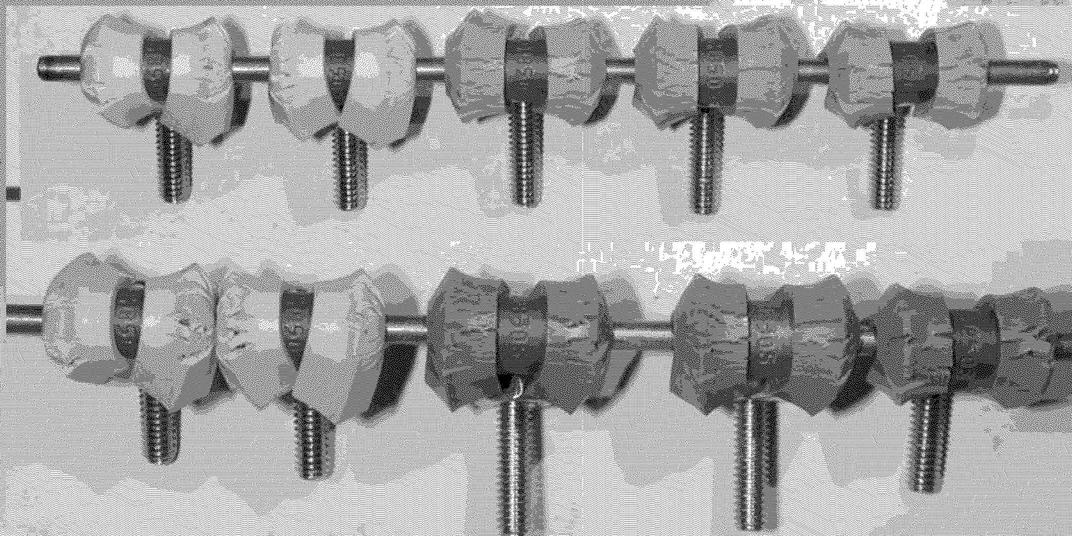




Actuator Endurance Testing



Lab Test/Evaluation Projects (Contd)



Specimen 61 Post Ozone Exposure

Specimen 61 Post UV Heavy Exposure

Field Units On and Off Aircraft Developing Cracks

Navy PAX River Labs Evaluated the Effects of Ozone and UV

Navy Continuing Effort to Revise MIL-C-85052 Based On Lab Results

Document Improvements Include Additional Testing and Improved Quality Assurance Provisions

A Clamp Panel Meeting Held at Recent SAE G-3 on March 15 2004

The MIL-C-85052 Specification Update Is Scheduled to Be Completed by Oct 04.

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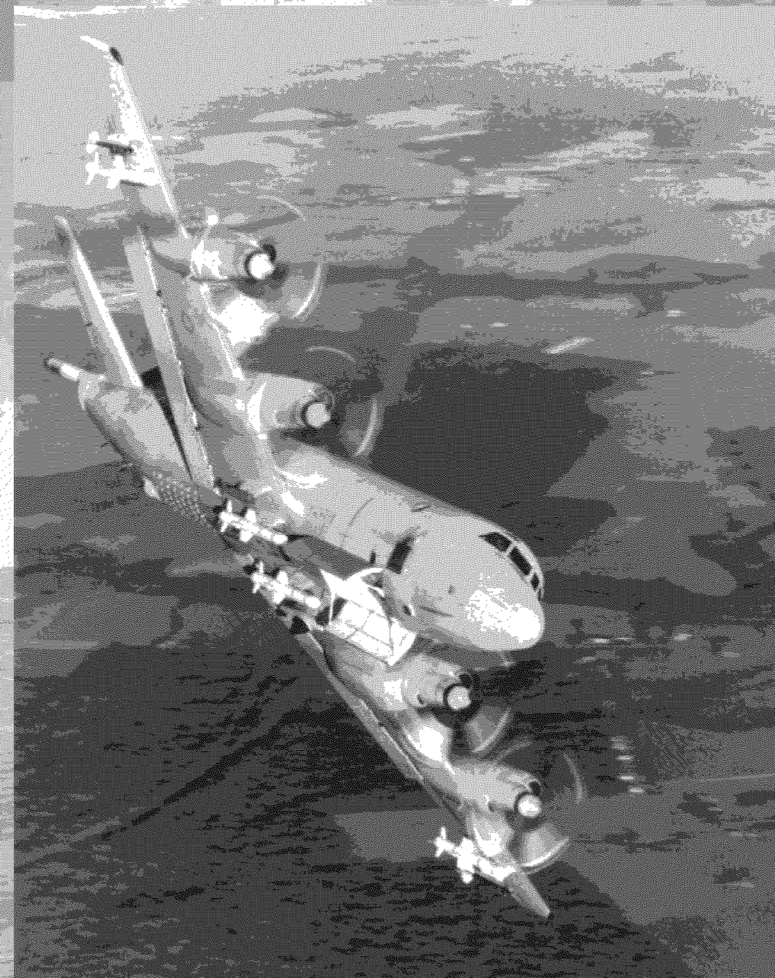
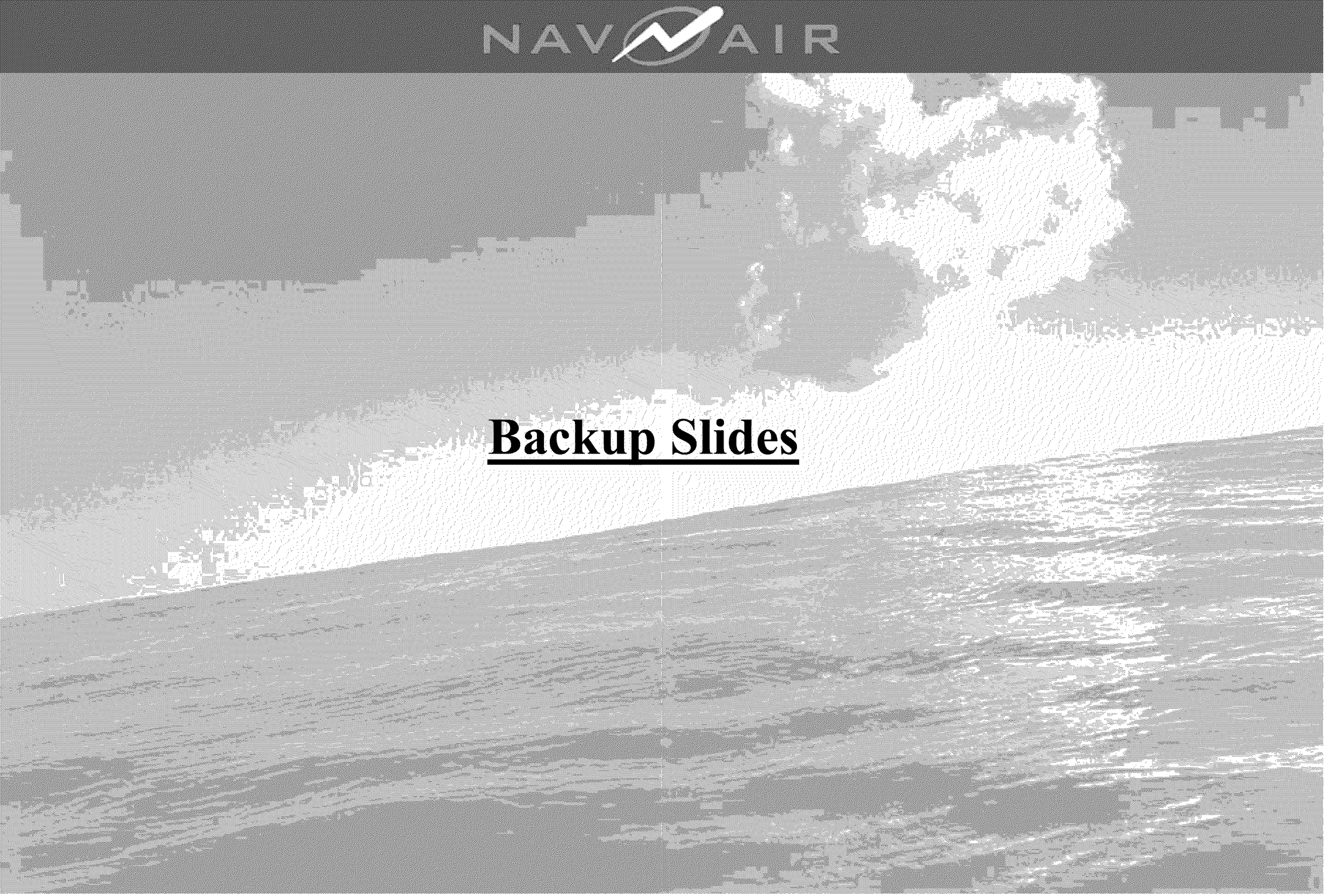
QUESTIONS???




NAVAIR
Backup Slides

MIL-C-85052
P-Clamp Cushion Test Analysis

Test Specimen Clamp Cushions:

- Clamps separated into 6 groups
  - 3 Groups of -2 clamps From QPL manufacturers (Umpco, T/A, J and M)
  - 3 Groups of clamps from airframe companies (Boeing Long Beach, Boeing Philadelphia, Korean Aircraft Industry)
- Clamps from QPL sources were new, -2 size
- Clamps from airframe companies were random and unused
  - Known manufacturers
  - Various sizes
  - Some lot identification
  - Unknown Manufacture date
  - Clamps in new condition, believed to be unused

Test Sequences:

One 5 clamp assembly from each of the 6 groups completed each of the following test sequences:

- Sequence A: Preconditioning, Ozone, UV Light, UV Medium, UV Heavy
- Sequence B: Ozone, UV Light, UV Medium, UV Heavy
- Sequence C: UV Medium, Preconditioning, Ozone
- Sequence D: UV Medium, Ozone

Test Procedure:

Preconditioning and Ozone levels per MIL-C-85052.

- Ozone: 600 pphm ozone for 6 hours at 125 F
- Preconditioning: 212 F for 70 hours

UV test per ASTM G154 without rain or humidity

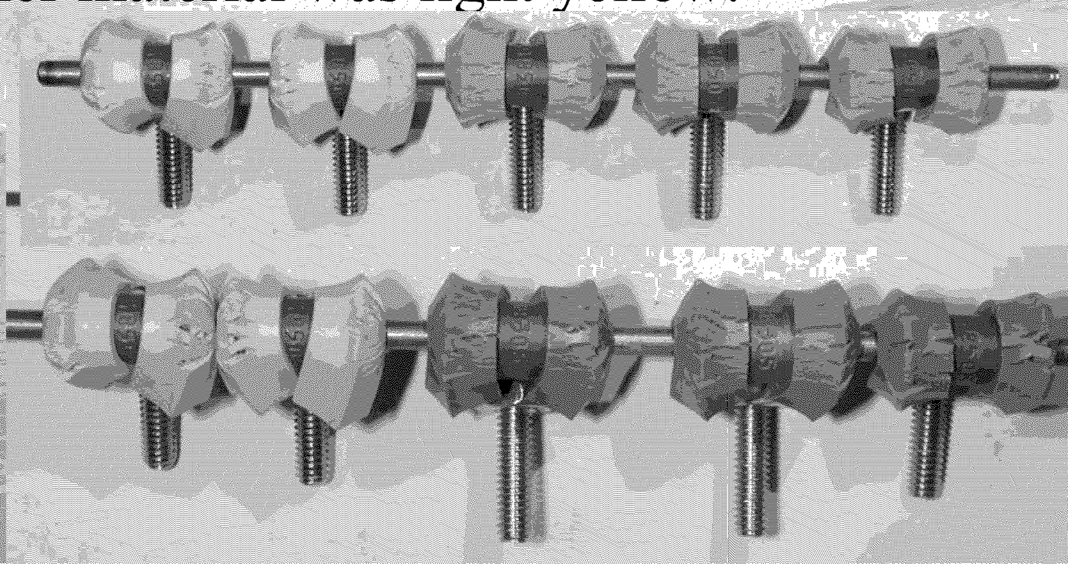
- UV Light is 72 hours exposure
- UV Medium is 120 hours exposure
- UV Heavy is 168 hours exposure

UV and Ozone Effects on Cracking:

- All clamp cushion cracking occurred during the ozone test.
- Cracking did not progress in subsequent tests
- No cushion cracking occurred during UV tests
- More ozone cracking occurred when there was no preconditioning. Preconditioning appears to help clamps pass ozone test.
- More clamps from airframers cracked than clamps from manufacturers. Suspect poor quality control.
- One Clamp manufacturer had no ozone cracking. Therefore the current MIL-C-85052/1 clamp cushion specification has achievable requirements.
- Clamps obtained from airframers gave similar results to clamps provided by manufacturers.

Color Change

- Most of clamp cushion color darkening occurred during exposure to light UV phase. Any surface effects of UV exposure occurs quickly and does not progress.
- Typically, medium and heavy UV exposure added little if any color change to the cushions.
- Cushion color darkening effected surface pigmentation only; inner material was light yellow.



Specimen 61 Post Ozone Exposure

Specimen 61 Post UV Heavy Exposure

Plan Forward

1. Change MIL-C-85052 specification as follows:
   - Full qualification testing is required if manufacturer changes cushion supplier or cushion material formulation.
   - Double number of samples ozone tested for QPL procedure, 5 with preconditioning and 5 without preconditioning
   - Quality Assurance testing is required regardless whether processes are changed or not. Definition of "Lot" and lot sampling should be strengthened. Possibly require QA for ozone, hardness, strength, tests after a set number of clamps produced, irregardless of size.
2. Re-qualify All QPL Companies
3. Turn QPL specification over to SAE.

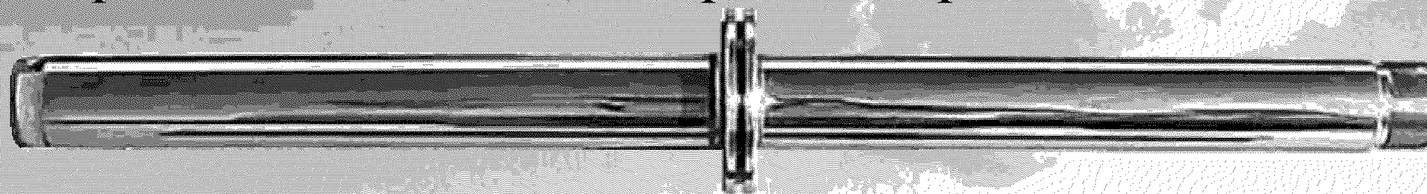
High Velocity Oxygen Fuel (HVOF)

Wear Resistant HVOF Rod Coatings

- High Velocity Oxygen Fuel (HVOF) applied wear resistant coatings are best practice for recent military and commercial flight control actuators.
- HVOF applied powder metal coating process is also less toxic than traditional chrome plating process.
- Super-finished HVOF surface finish is critical because wear resistant HVOF rods will not polish up in service.

Status of HVOF Coating Efforts

- F/A-18 stabilator with HVOF coated rod has been qualified with chrome equivalent performance.



- HVOF coated P-3 weapons bay door actuators in service for 2 years with no corrosion observed.
- F/A-18 TEF actuator qualified with one chrome rod and one HVOF rod showed equivalent leak-free performance of both rods.

Seal Upgrade

Heat Resistant Static Fluorocarbon Seals

- Many existing components designed before widespread use of fluorocarbon seals.
- In 1996 NAVAIR evaluated performance and endurance of several F/A-18 flight control actuators packed with fluorocarbon seals.
- High and low temperature performance was excellent but some dynamic seals showed minor damage.
- A Canadian F/A-18 has been operating since 1997 with fluorocarbon packed flight control actuators.

Spring Energized PTFE Dynamic Seals

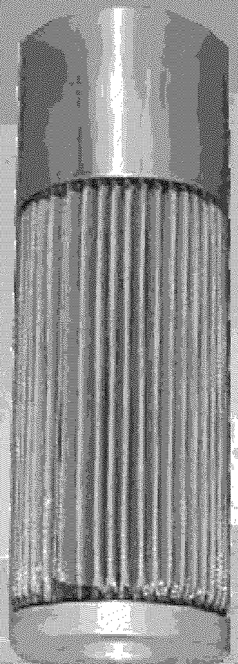
- Spring energized seals provide consistent leak-free performance at high and low temperatures.
- In 2000, NAVAIR endurance testing showed performance of spring energized seals far superior to elastomer seals.
- Seal kits with fluorocarbon static seals and spring energized PTFE dynamic seals have been developed for several components.

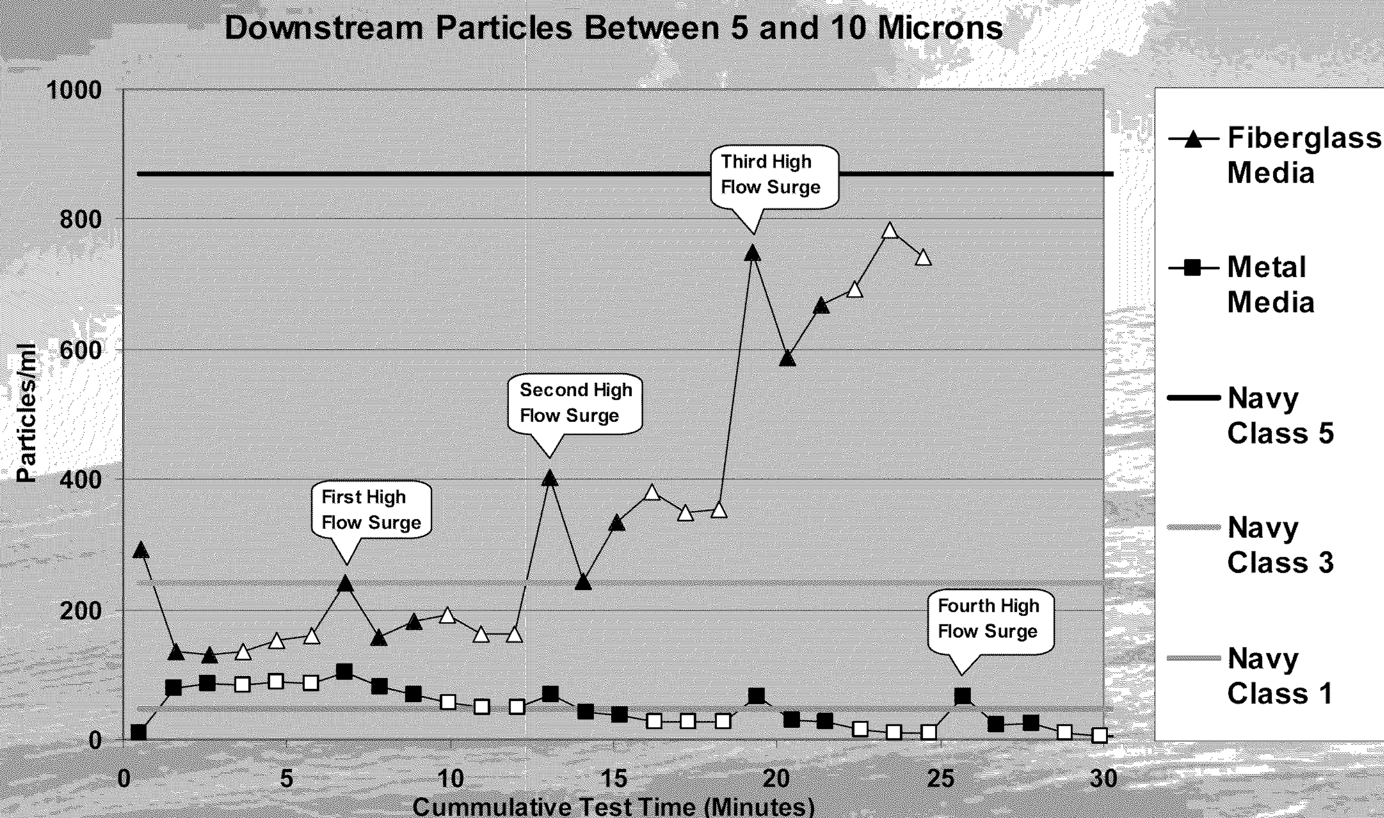
Status of Heat Resistant Upgrade Efforts

- Upgraded F-14 stabilator and wingsweep swivels have been fielded with excellent results.
- Seal kits from three vendors have been qualified on the F/A-18 C/D stabilator actuator and are ready for retrofit.
- Similar efforts on F/A-18 C/D and H-60 flight control actuators are also in work.

Dynamic Filtration

Dynamic Filter Efficiency and Fluid Cleanliness





- Media degradation causes system dirt levels to increase with time.

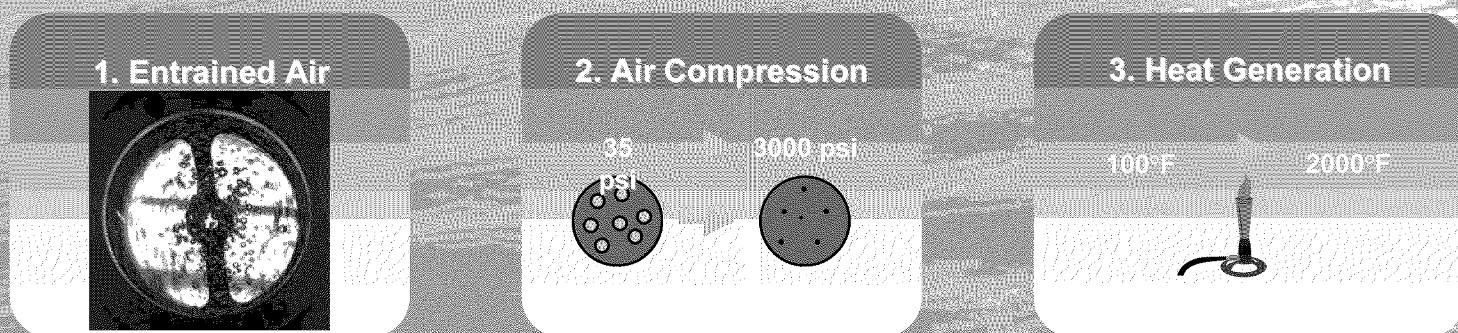
Update of MIL-F-8815 Filter Spec

- Filter specification was last revised in 1976 prior to widespread use of particle counters.
- Intent of specification was to evaluate media performance and degradation, but steady flow, single pass gravimetric test method is not adequate.
- Existing method gives an estimate of new filter efficiency in a steady flow environment.
- Alternate test method to evaluate filter efficiency under dynamic flow.
- Alternate method for measuring fluid cleanliness and filter performance using particle counters.
- Investigate alternate materials and methods for qualification and vendor lot testing.
- This effort will extend and modernize the MIL-F-8815 without affecting existing products.

NAVAIR

Air Contamination and Fluid Purification

- Many Navy hydraulic systems have undersized components in an effort to reduce system weight.
- Aggressive flying can easily overwhelm heat exchangers, causing excessive fluid temperatures.
- This condition is aggravated by air contamination.



Bleeding Details:

Maintainers report tendency to collect air between flights requires frequent reservoir burping and bleeding to manage air contamination levels.

Coupling Details:

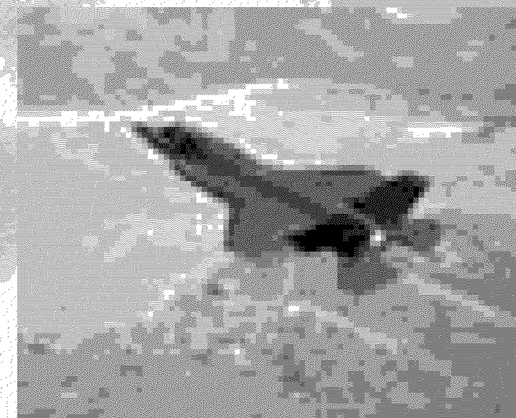
Existing couplings prevent fluid loss under pressure, but post-flight cooling pulls dirty outside air through the coupling.

An improved vacuum tight coupling with redundant elastomer and metal lap seals in both the coupling and the cap prevents this in flow of dirty outside air.

NAVAIR

Fluid Purification

Hydraulic Fluid Purification History



- Oil viscosity keeps air bubbles entrained.
- Effective air bleed takes several hours of start and stop operation.
- 15 minutes with a purifier is more effective than 3 hours with a ground cart alone.
- With air to the fluid, some surfaces can be moved almost a foot by hand.
- After purification, surfaces are rock solid (moving maybe 1/2 inch by hand).
- Fluid samples from hot jets are typically frothy, not clear fluid.


Future Trends in
Flight Control Actuation
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216
BOEING

Electric Flight Control Actuators

"If I had thought about it, I wouldn't have done the experiment. The literature was full of examples that said you can't do this."

--Spencer Silver on the work that led to the unique adhesives for 3-M "Post-It" Notepads.

"The concept is interesting and well-formed, but in order to earn better than a 'C', the idea must be feasible."

--A Yale management professor in response to student Fred Smith's paper proposing reliable overnight delivery service (Smith went on to found Federal Express Corp.)

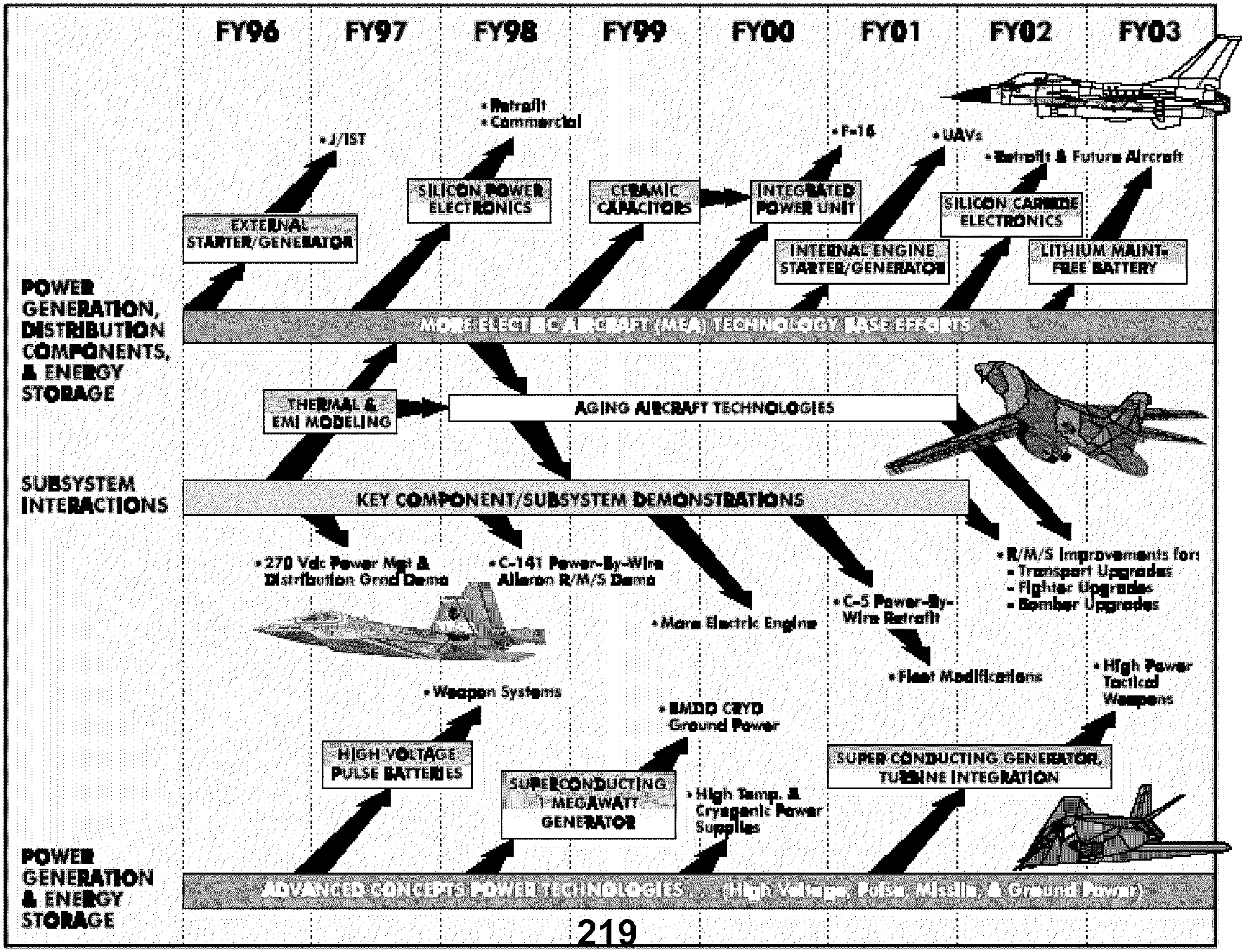
User Needs

- Increased System Reliability
- Reduced Maintenance Times
- Reduced Operation and Support Cost
- Improved Aircraft Survivability

Objectives

- Develop breakthrough Technologies, which enable revolutionary war fighter capabilities
- Technology insertion to extend today's fleet to meet tomorrow's war fighter needs

Aerospace Power



Vision

- "Pump electrons" instead of hydraulic fluid, oil, or fuel
  - Develop a "distributed control system"
    - Eliminates the need for on-engine hydraulic systems, gearboxes, and associated plumbing
  - Develop Internal engine starter/generator technology
    - Eliminates the central hydraulic unit, the power takeoff shaft, and the gearbox.

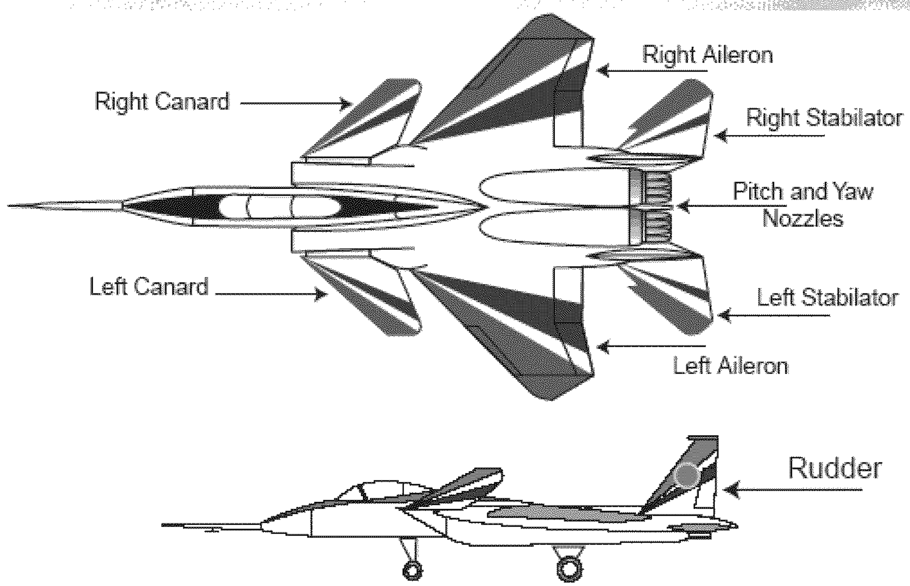
"More Electric" Payoff

- Reduce support equipment and costs
- Improve current aircraft effectiveness
- The technology direction of opportunity for
  - Uninhabited Aerial Vehicles (UAVs)
  - Commercial Aviation
  - Electric Vehicles
  - Numerous other Commercial Applications
  - Advanced Weapon Concepts.

What does this mean for Flight Control Actuation?

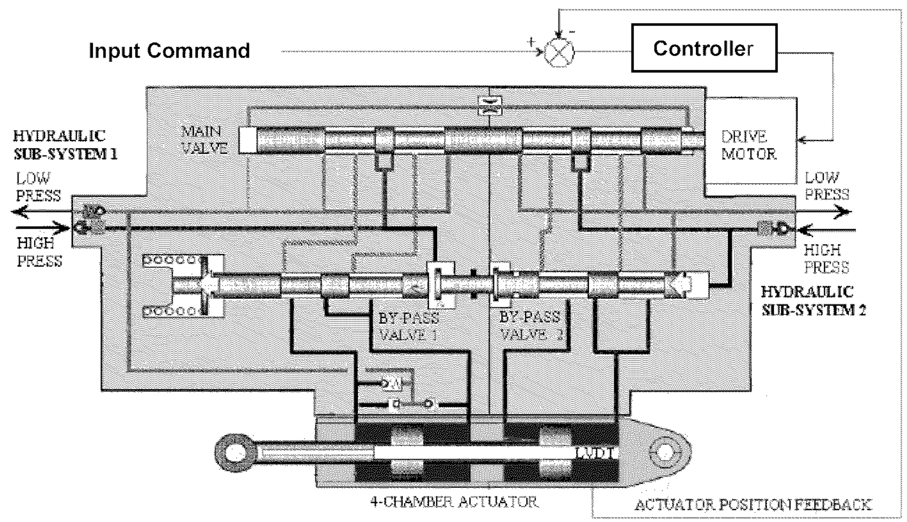
Power-by-wire (PBW) actuation is the next major breakthrough in aircraft control. Just as the fly-by-wire flight control system eliminated the need for mechanical interfaces, power-by-wire actuators eliminate the need for central hydraulic systems. Control power comes directly from the aircraft electrical system.

State of the Art Actuators



Key Performance Parameters

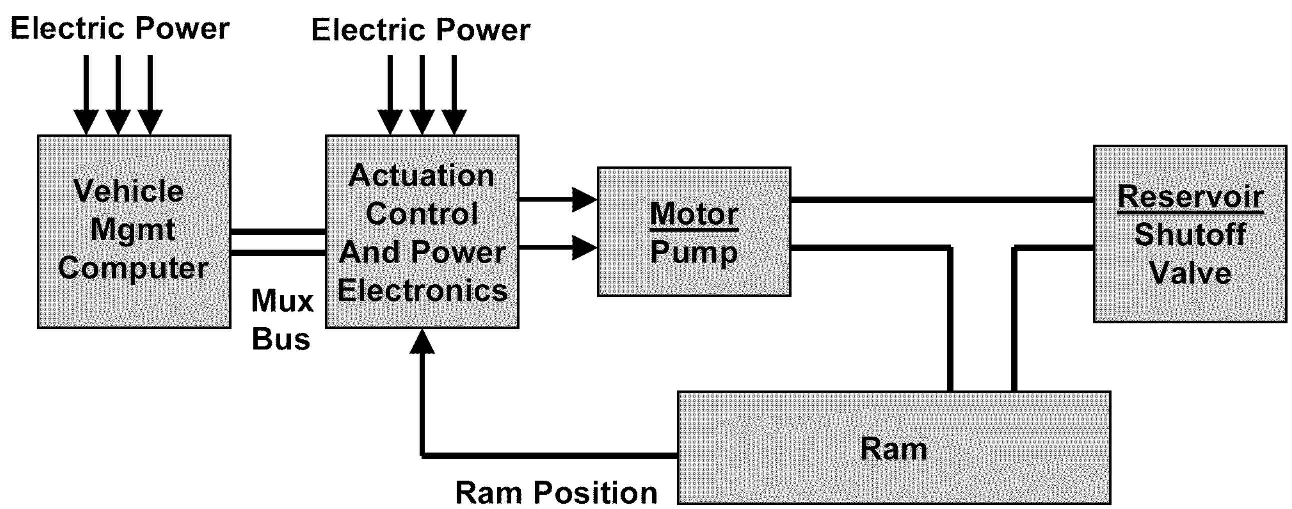
- Stall Load
- Maximum Rate
- Frequency Response
- Dynamic Stiffness
- Failure Transients
- Input Power vs. Load



Electrohydrostatic Actuator (EHA)

Fixed Displacement

Configuration



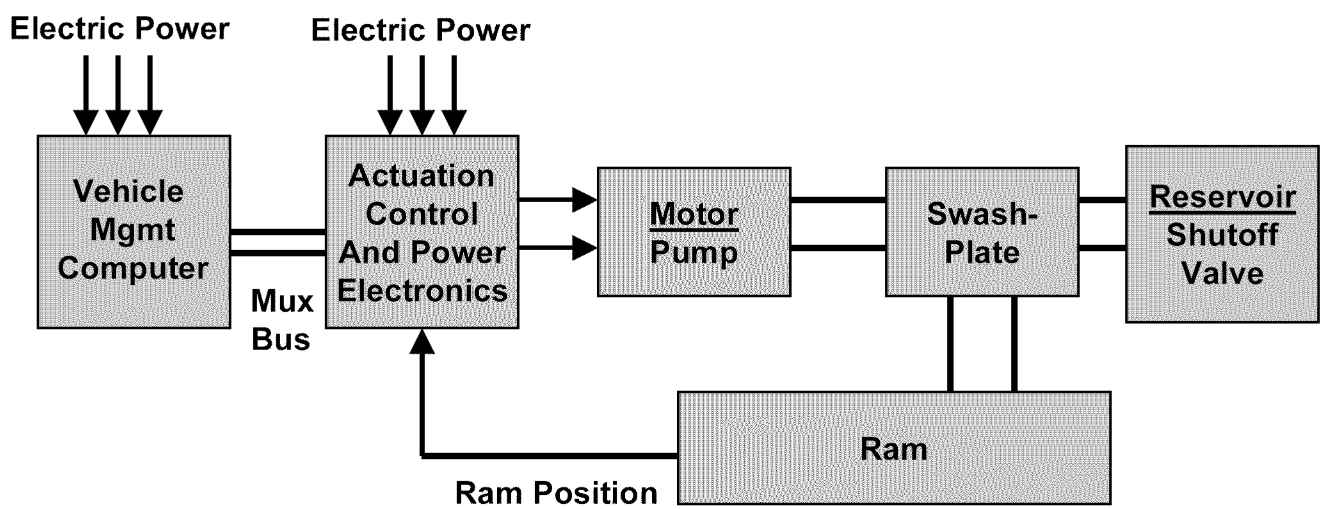
Characteristics

- Motor must reverse rotation to reverse direction
- Electronic controller is required to control the speed and direction of motor rotation
- Motor must be stalled to hold the flight control surface against the airstream

Electrohydrostatic Actuator (EHA)

Variable Displacement

Configuration

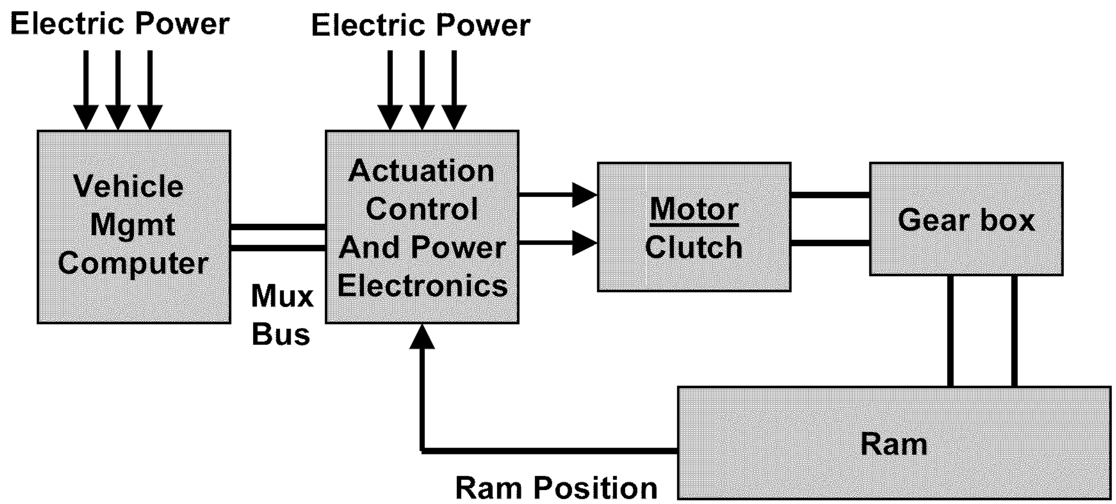


Characteristics

- Motor Turns in one direction regardless of actuator direction
- Motor rotates at constant speed even at no load

Electromechanical Actuator (EMA)

Configuration



Characteristics

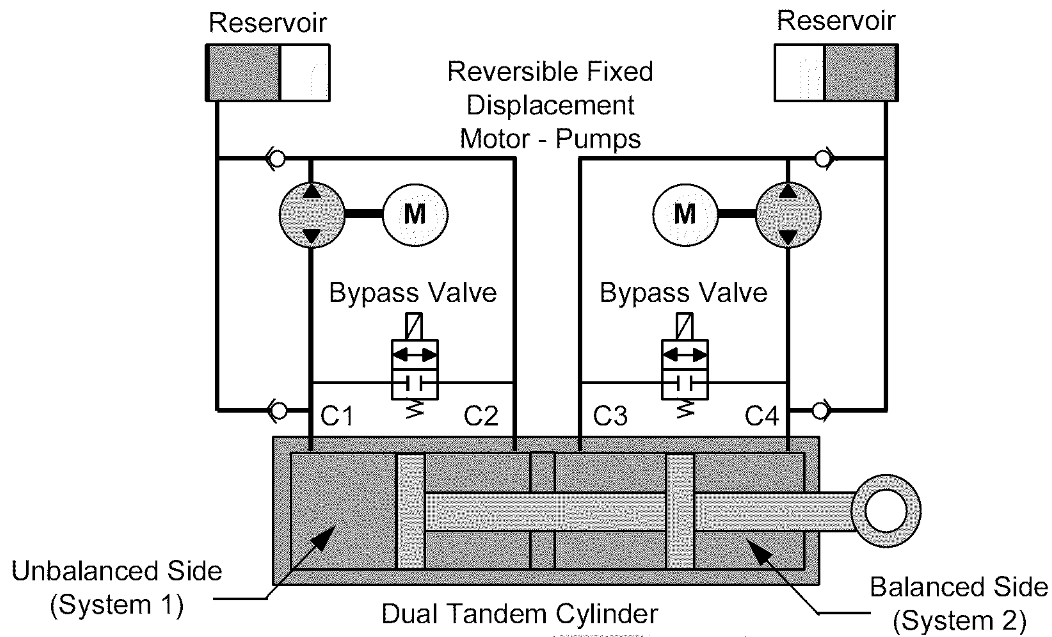
- Motor must reverse rotation to reverse direction
- Electronic controller is required to control the speed and direction of motor rotation
- Motor must be stalled to the hold flight control surface against the airstream
- Susceptible to failure mode that could jam the control surface in a deflected position

Flight Control Actuation

- **Architecture Definition Drivers**
  - Safety
    - Complete loss of power
    - Flutter risk
    - Minimize effect of the loss of power sources
    - Minimize vulnerability to engine or tire burst, mid-air collision, battle damage, etc...
  - Maintenance costs
  - Weight, at aircraft level, actuation plus power sources

- **Key Performance Parameters**
  - Frequency Response
  - Static Stiffness
  - Dynamic Stiffness
  - Loaded Rate
  - Input Power vs. Load
  - Electromagnetic Emissions

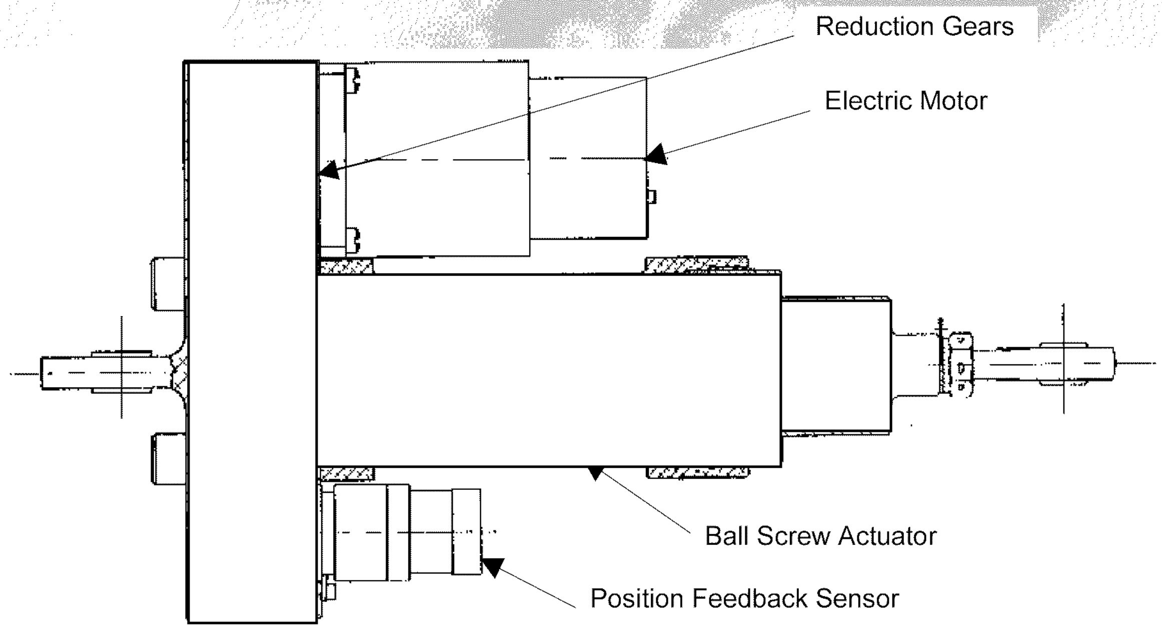
Electro-Hydrostatic Actuator (EHA)



ADVANTAGES
- REMOVE CENTRALIZED HYDRAULICS
- CAN PROVIDE REDUNDANCY AT SURFACE

ISSUES
- SERVICING (STILL FLUID LOOP)
- PERFORMANCE (BANDWIDTH)
- COOLING PENALTIES
- FAILURE MODES (FLUID LOOP)

Electro-Mechanical Actuator (EMA)



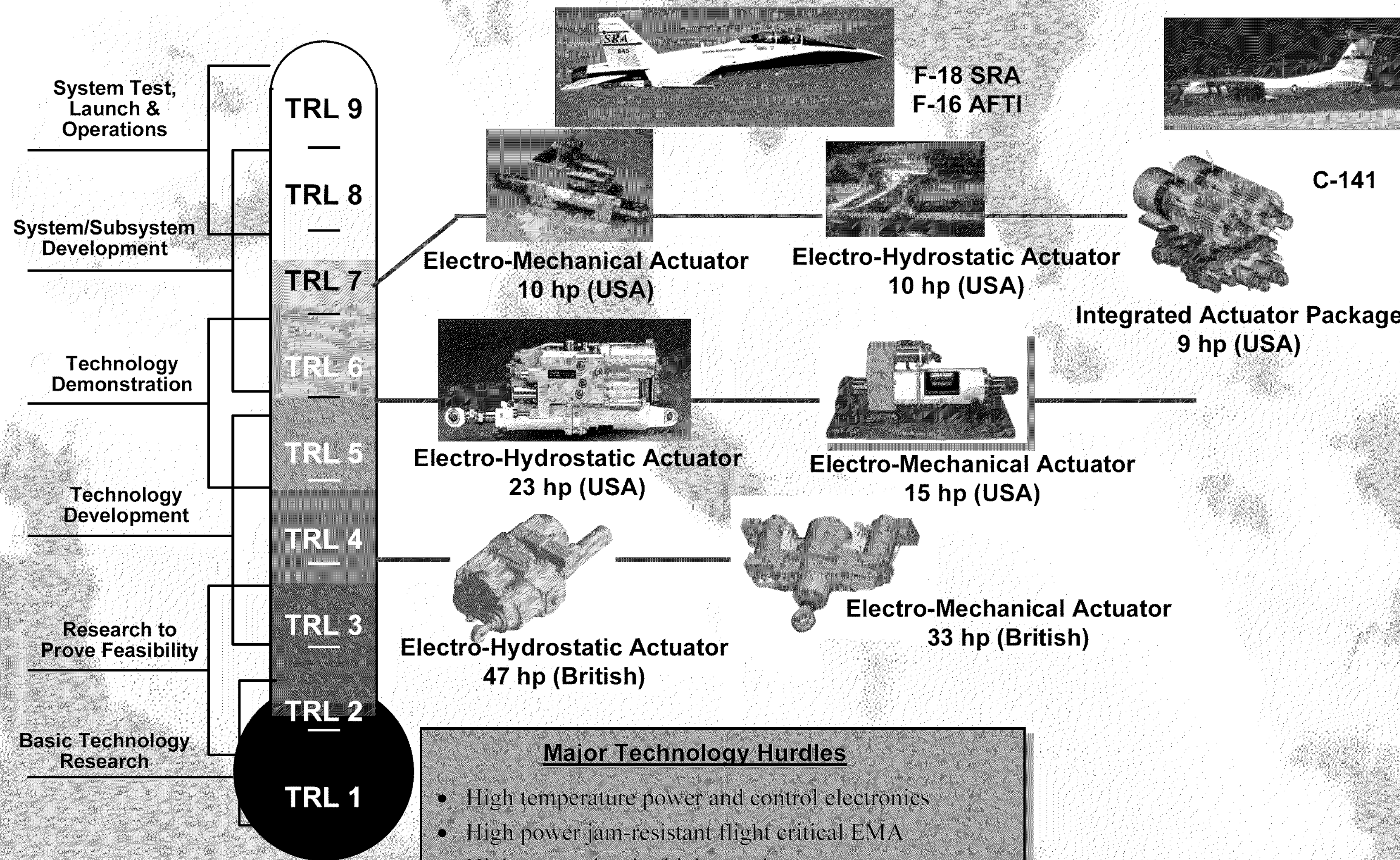
ADVANTAGES

- REMOVE HYDRAULICS ENTIRELY
- IMPROVED SUPPORTABILITY OVER EHA
  - NO SERVICING
  - LONGER SHELF LIFE

ISSUES

- LIMITED REDUNDANCY (SIMPLEX)
- PERFORMANCE (BANDWIDTH)
- COOLING PENALTIES
- FAILURE MODE (PURE MECHANICAL)

Test Readiness Level of Electric Actuation



Major Technology Hurdles

- High temperature power and control electronics
- High power jam-resistant flight critical EMA
- High power density/high speed motors
- Establish electric actuation reliability

What's in the Future?

- Fly by Light Will Be Required to Save Weight and Cost in an Increasingly Hostile EMI Environment
- High Power EHAs for Future More Electric Aircraft
  - Eliminate Gearboxes
  - Subsystem Integration
  - Improve Efficiency

Electric Actuation
Summary

Objective
- Eliminate Central Hydraulic System
- Eliminate AMAD
- Power on Demand
- Fault Tolerant Design
- Reduce Ground Support Equipment

Results in
- Reduced Power Consumption
- Improved R&M
- Decreased Weight
- Reduced Vulnerability and Improved Survivability

Bottom Line: War Fighter Capability

- Right Materiel, Right Place,
- Right Time, at the Right Cost -
  - *All The Time*


Thank You

Overview of BSN Hydraulic Fluid Contamination

Shashi Sharma, PhD
Air Force Research Laboratory
Wright Patterson AFB, OH

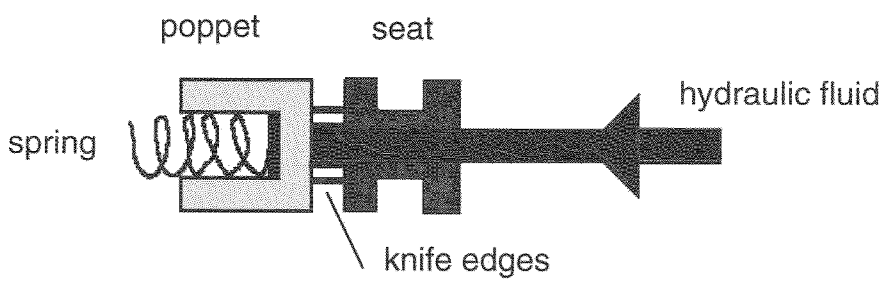
Overview of BSN Hydraulic Fluid Contamination

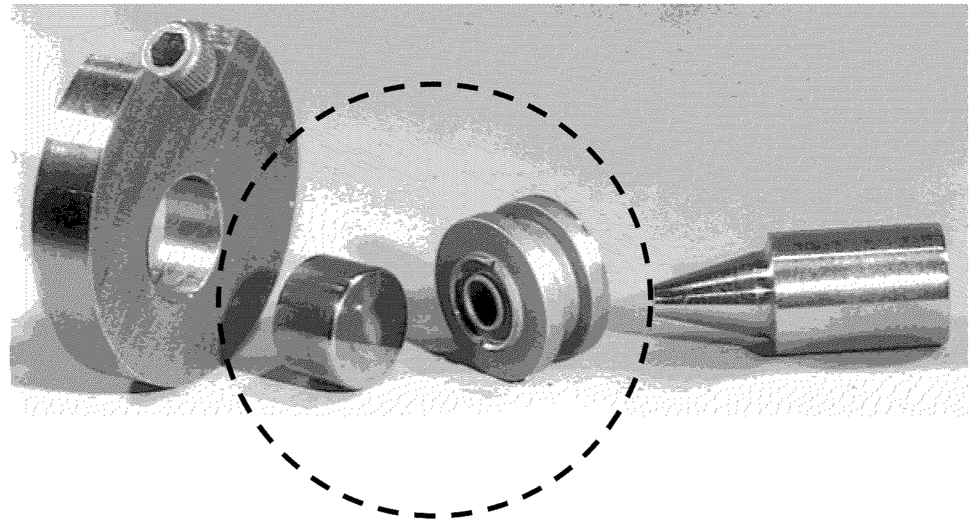
- Water
  - Formation of ice crystals
  - Corrosion
  - Fluid degradation
- Particles
  - Wear and tear of components
  - System malfunction
  - Filter clogging
- Solvents
  - Sticking servo valves in aircraft
  - Affect fluid properties

Can be removed by purifiers

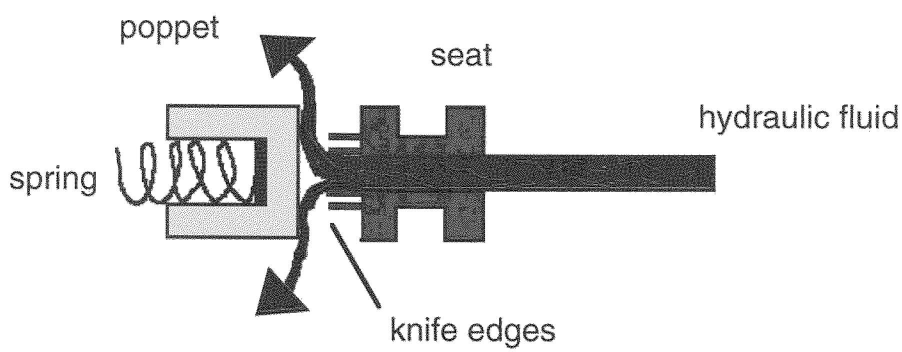
- BSN (rust-inhibitor in storage fluids, MIL-PRF-6083 and -46170)
  - Sticking servo valves in aircraft (AF, Army)
  - Filter clogging (Navy)
  - Increased component wear (Navy)
  - Hazardous waste

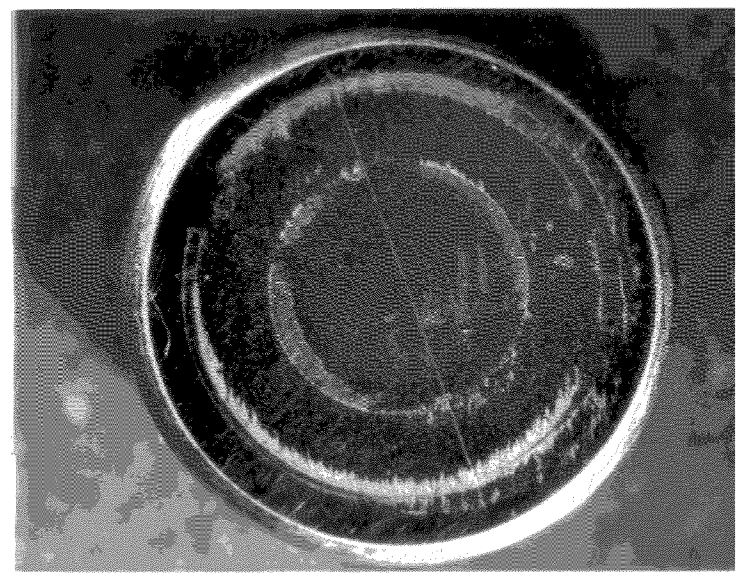
INLET CHECK VALVE





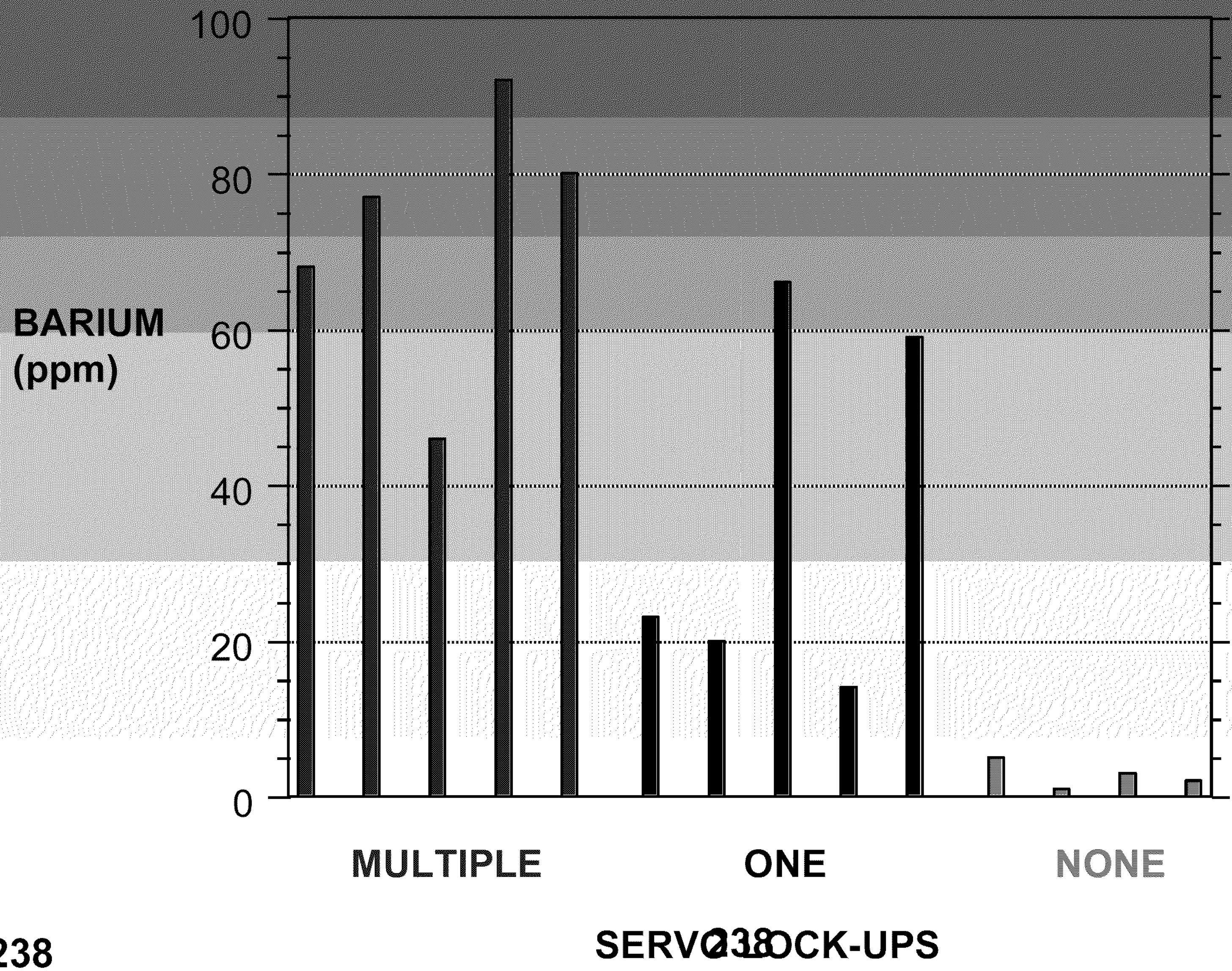
VALVE CLOSED / STUCK





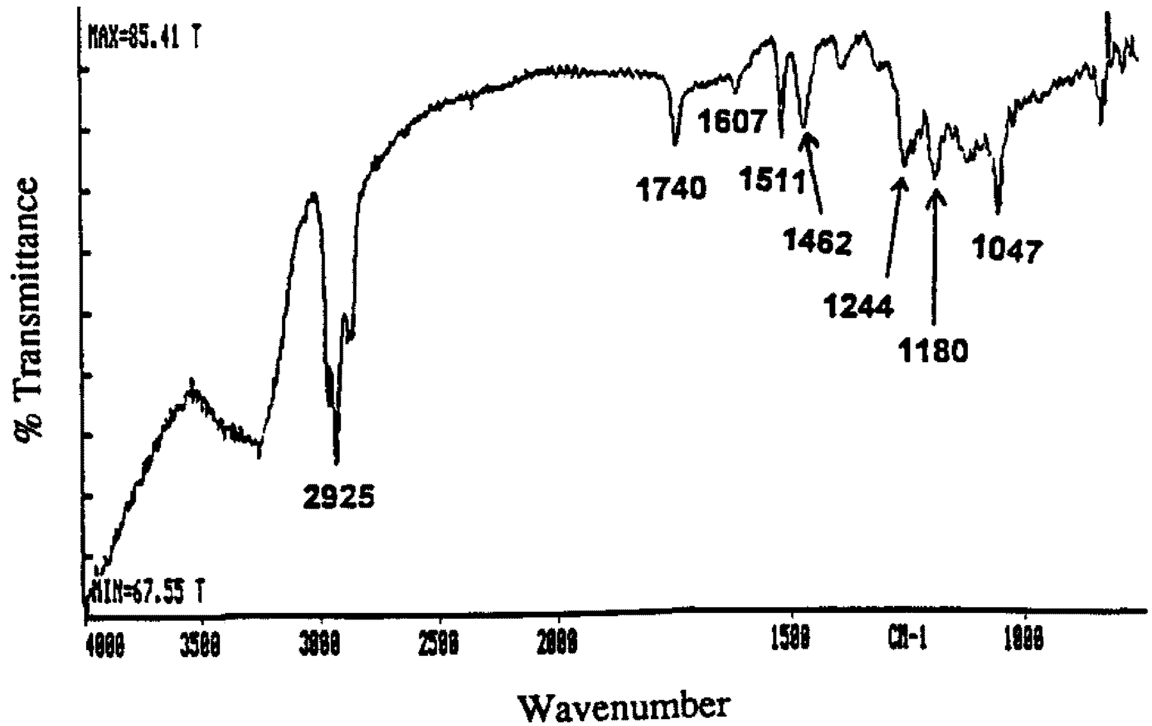
VALVE OPEN / NOT STUCK

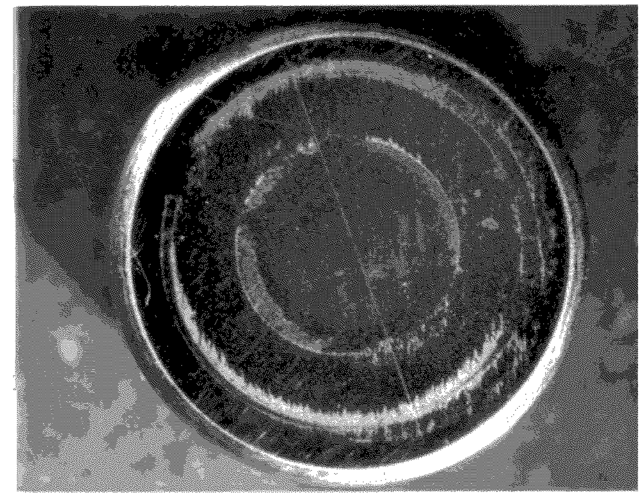
Overview of BSN Hydraulic Fluid Contamination



238

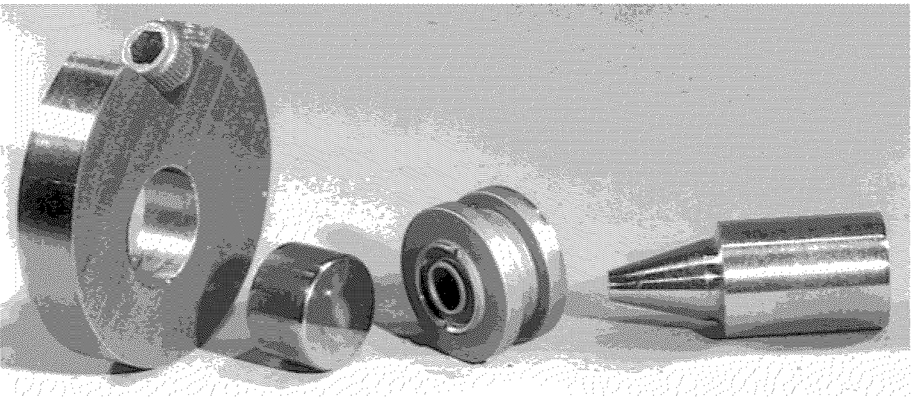
Overview of BSN Hydraulic Fluid Contamination

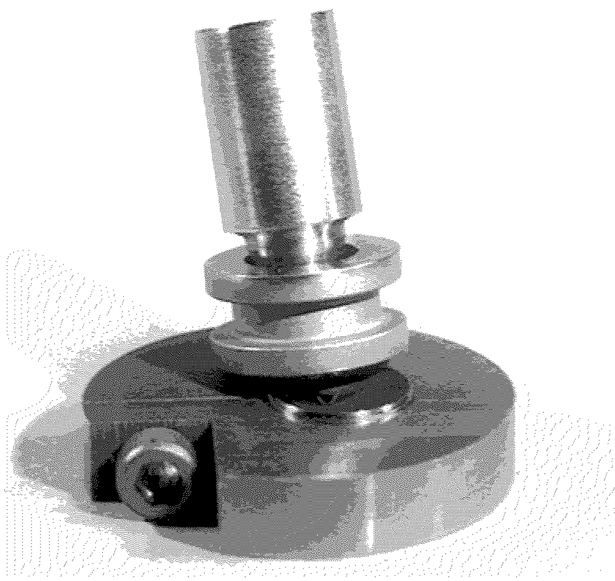


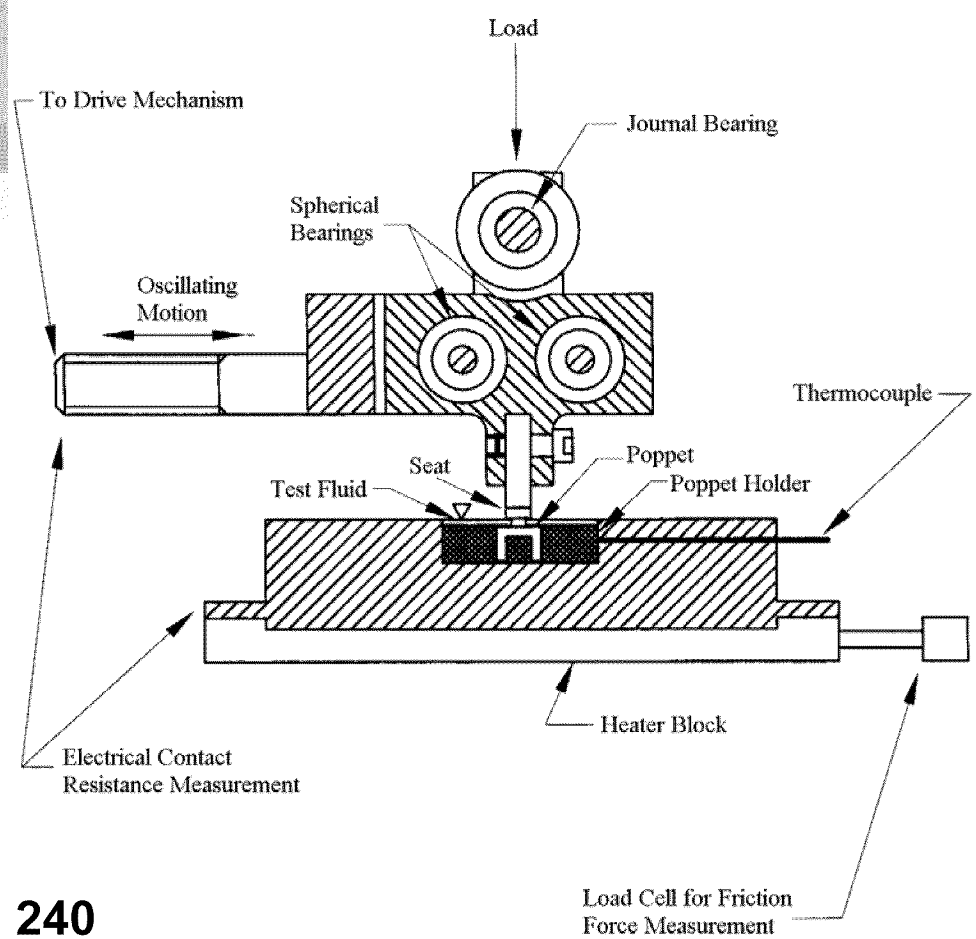


GAM-FTIR Spectrum of Poppet Face of a Stuck Valve after Rinsing with Hexane

Simulation of Deposit Buildup on Poppet Faces







Simulation of Deposit Buildup on Poppet Faces

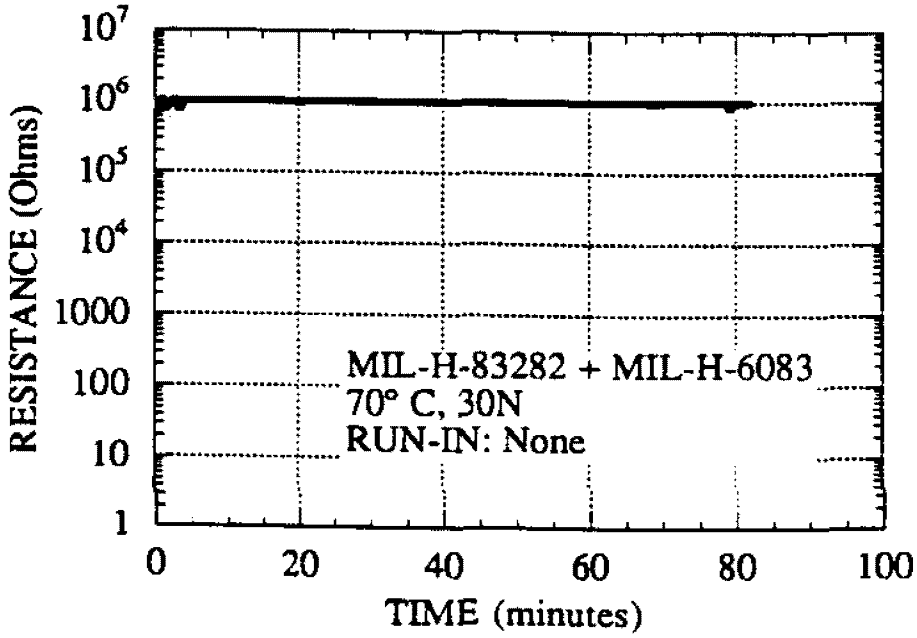
Test Fluid:

1 part MIL-H-6083 + 15.7 parts MIL-PRF-83282 (200 ppm Ba)

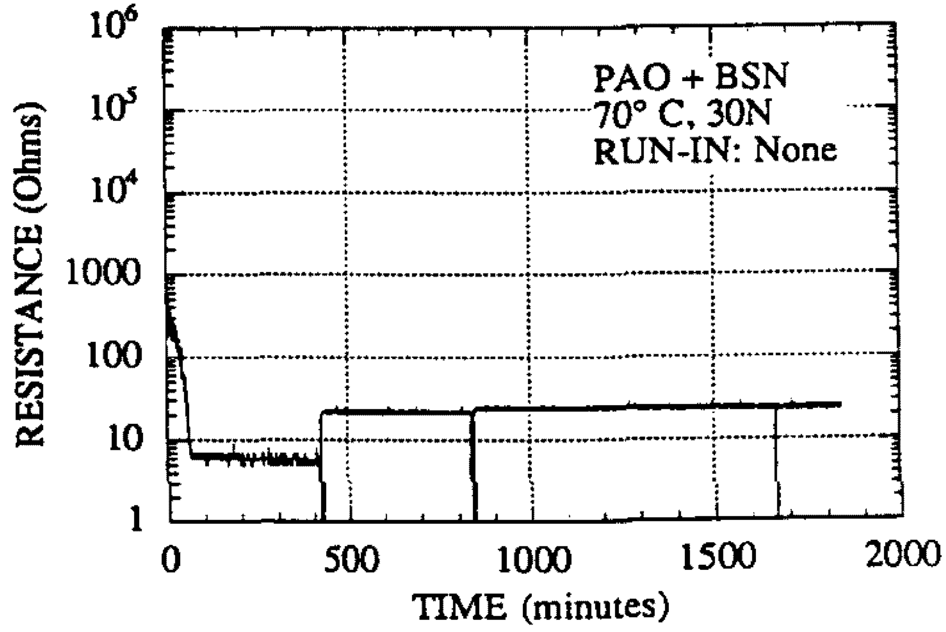
Test Conditions

- Oscillating frequency: 10 Hz
- Stroke: 0.1 mm
- Temperature: 70° or 100° C
- Load: 10, 30 or 50 N
- Duration: Varied
- New poppet and seat used for each test

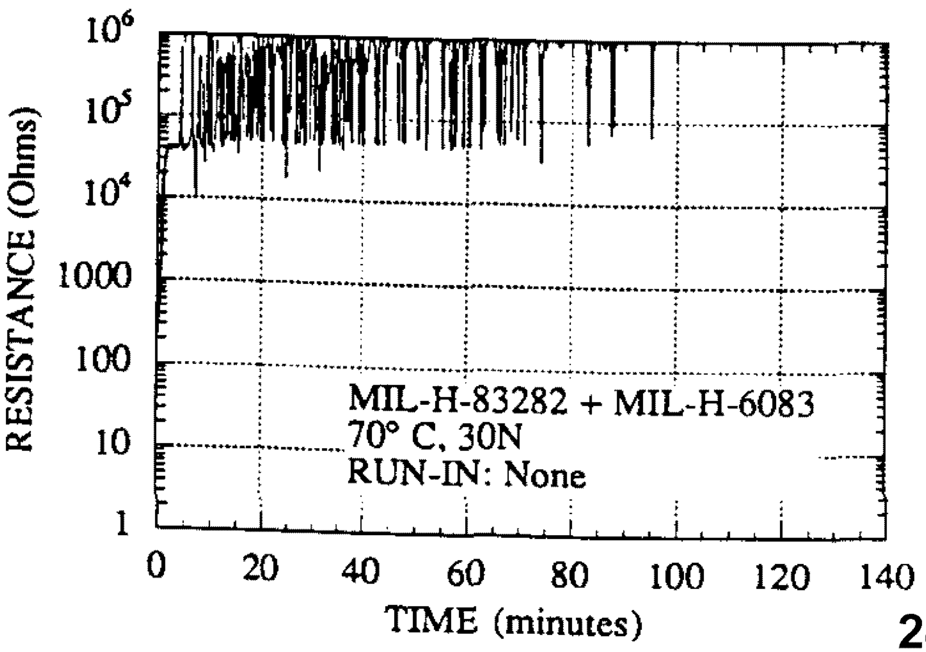
Friction force and electrical contact resistance measured throughout the test



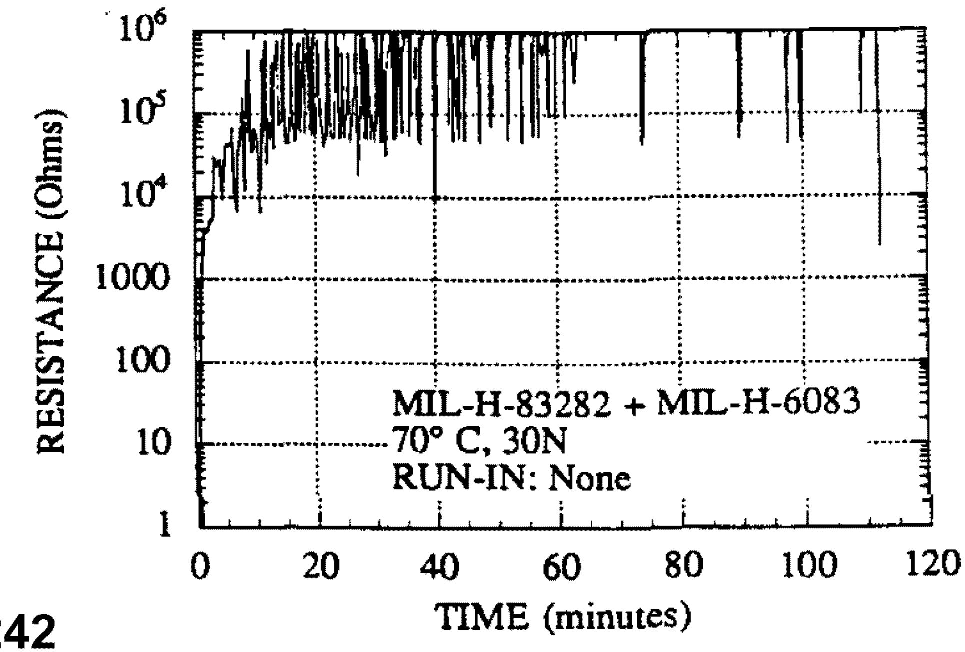
TEST NO. -9



TEST NO. -10

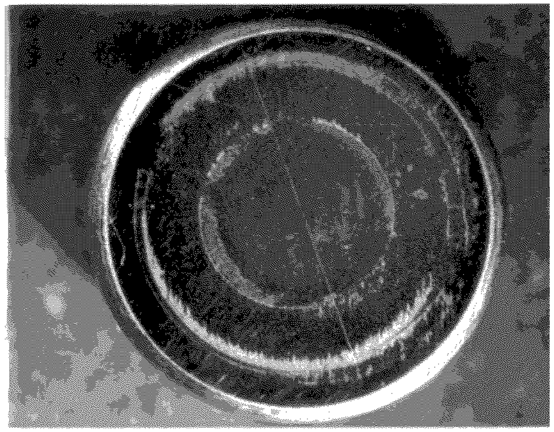


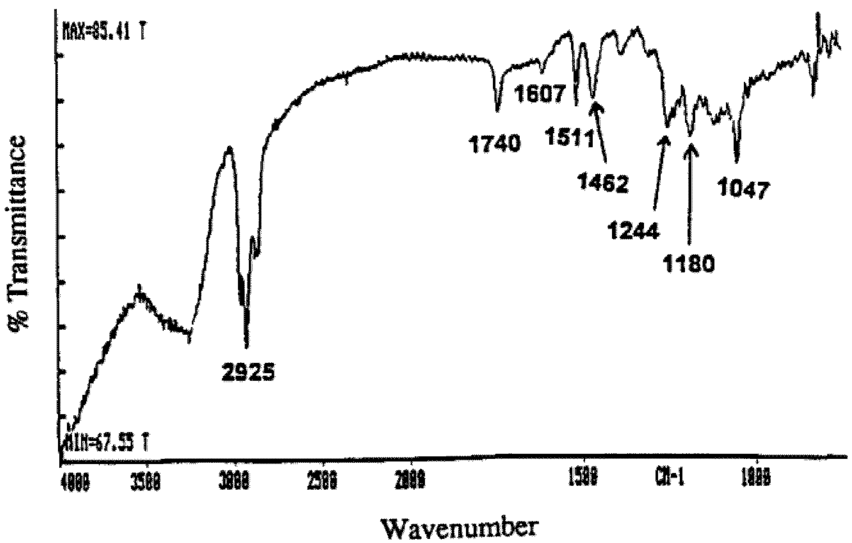
TEST NO. -11



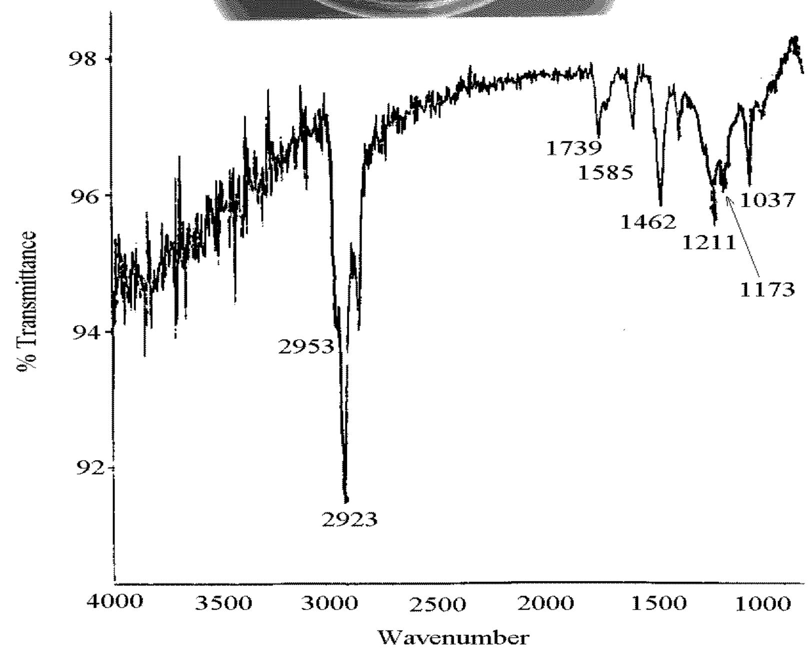
TEST NO. 12

Overview of BSN Hydraulic Fluid Contamination





GAM-FTIR Spectrum of Poppet Face of a Stuck Valve after Rinsing with Hexane



GAM-FTIR Spectrum of Poppet Face from Laboratory Simulation

Overview of BSN Hydraulic Fluid Contamination

Summary

- BSN contamination in hydraulic systems has caused operational problems such as sticky valves, clogged filters and excessive wear

- Should we discontinue the use of BSN containing fluids for component storage ?

Stay tuned for Lois's presentation

PALL Aerospace

TECHNICAL PRESENTATION

Aircraft Fluid System Health Monitoring

Gary Rosenberg

Marketing Manager

Pall Aeropower Corporation

June 15, 2004

Agenda

The filter element can be used as a fluid system health monitor:

- Ease of system incorporation
- On condition maintenance
- Early indicator of system problem
- Identify the problem source

Fluid System Health Monitoring

With over 50 years of experience applying fluid clarification systems, we have in depth knowledge on our products' sensitivity to in-system debris.

Sources of system debris include:

- Component Wear or Failure
- Environmental Contamination
- Fluid Breakdown
- Maintenance

Fluid System Health Monitoring

Goal:

- Enhance operational safety
- Increase mission availability
- Effective system maintenance

Reduce the Cost of Ownership

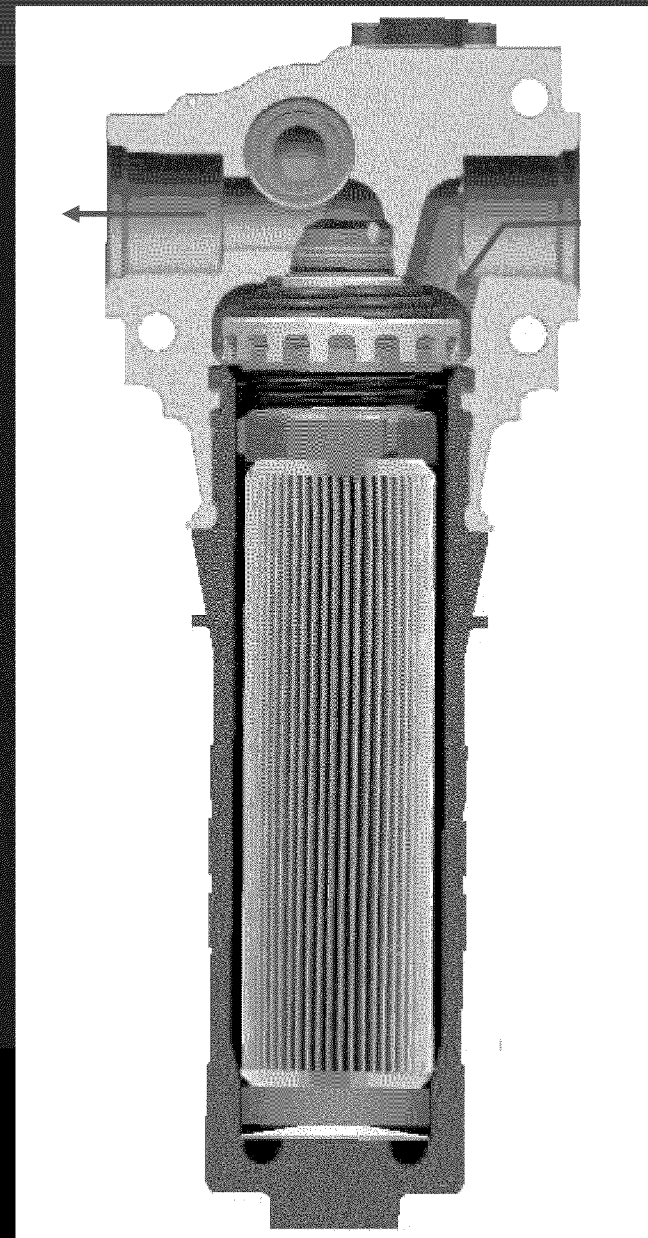
PALL Aerospace

Filter Elements Support Fluid System Health Monitoring

PALL Aerospace

Fluid System Health Monitoring

- Full system flow protection
- Removes environmental and system-generated debris
- Controls non-metallic as well as metallic particulate
- Large voids volume provides low pressure drop and required service life
- Filter exists in every major fluid system



Fluid System Health Monitoring

Conventional Installation:

- Indicates loaded filter element
- Indicates system in bypass

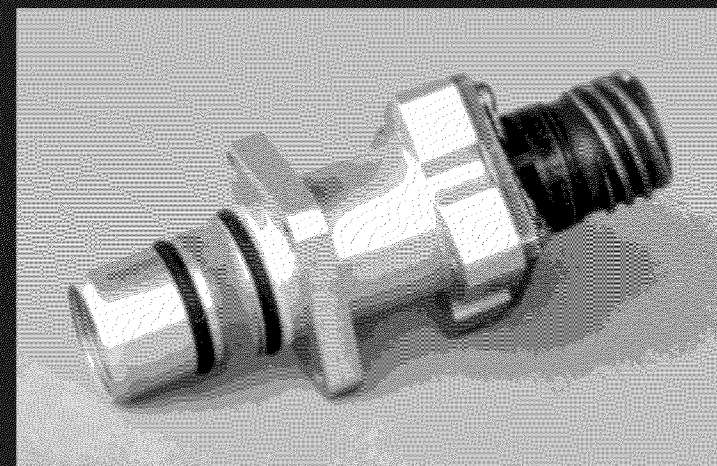
Fluid System Health Monitoring

Switch and Indicator Limitations:

- Proper actuation / operation cannot be determined until terminal pressure reached
- Wide actuation tolerance ($\pm$ 15%)
- Subject to cold start hysteresis
- Single point indication
- No prior warning before actuation

Necessitates Filter Element Change on a Time Interval Basis

Differential Pressure & Temperature Sensor



- No moving parts
  - Enhanced reliability
  - No components to wear
  - No reseat characteristics
- Continuous output confirms proper operation
- Compatible with low current requirements
- Replaces existing differential pressure device in existing port
- Incorporates temperature output

Differential Pressure & Temperature Sensor

Advantages:

- Continuously monitors pressure drop
- Continuous performance validation
- Improved indication tolerance ($\pm$ 1%)
- Negligible cold start hysteresis
- Built-in temperature sensor providing continuous thermal monitoring

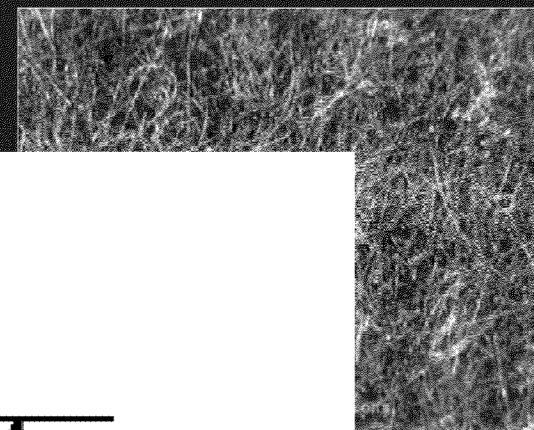
Differential Pressure & Temperature Sensor

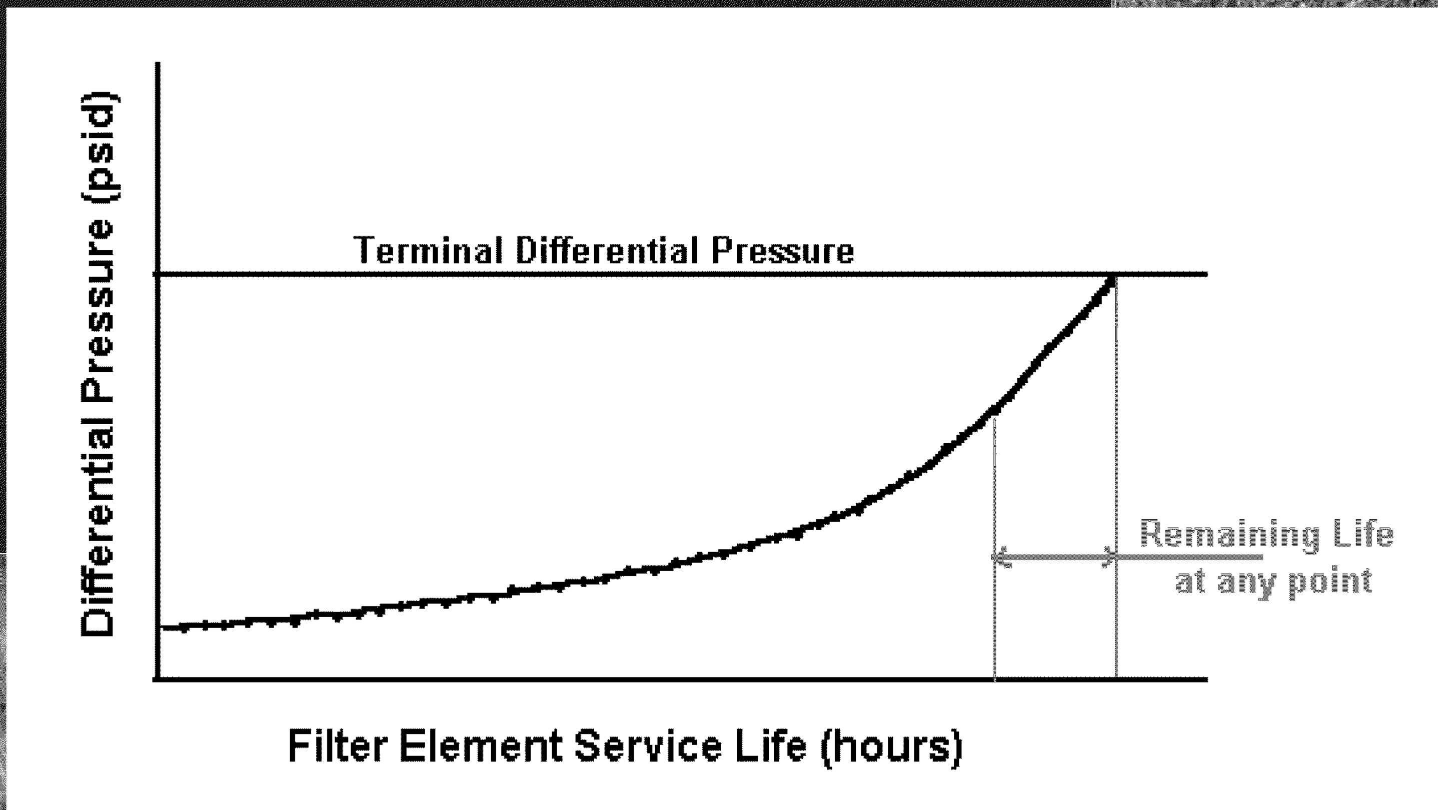
Additional Advantages:

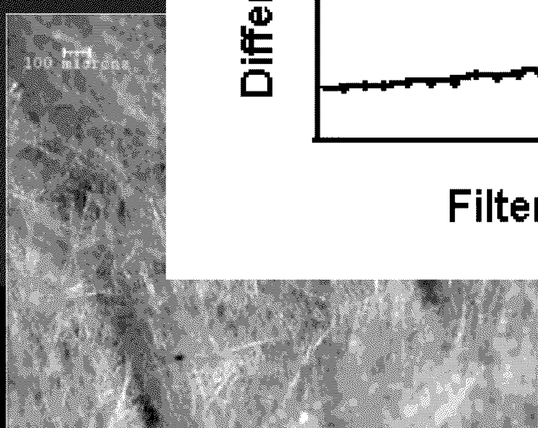
- Enables full utilization of the filter element
- Continuous monitoring of filter element performance enables accurate scheduling of filter element change enabling

  On-Condition Filter Servicing
- System performance limits can be changed without hardware change
- Reduces development & operating costs

On-Condition Servicing







Fluid System Health Monitoring

The natural equilibrium between operating system generated debris and in-system filtration permits the establishment of an expected filter service life.

During System Operation:

	Particulate	Filter Element
	Normal Ingression:	Expected Service Life
	Abnormal Ingression:	Reduced Service Life

Fluid System Health Monitoring

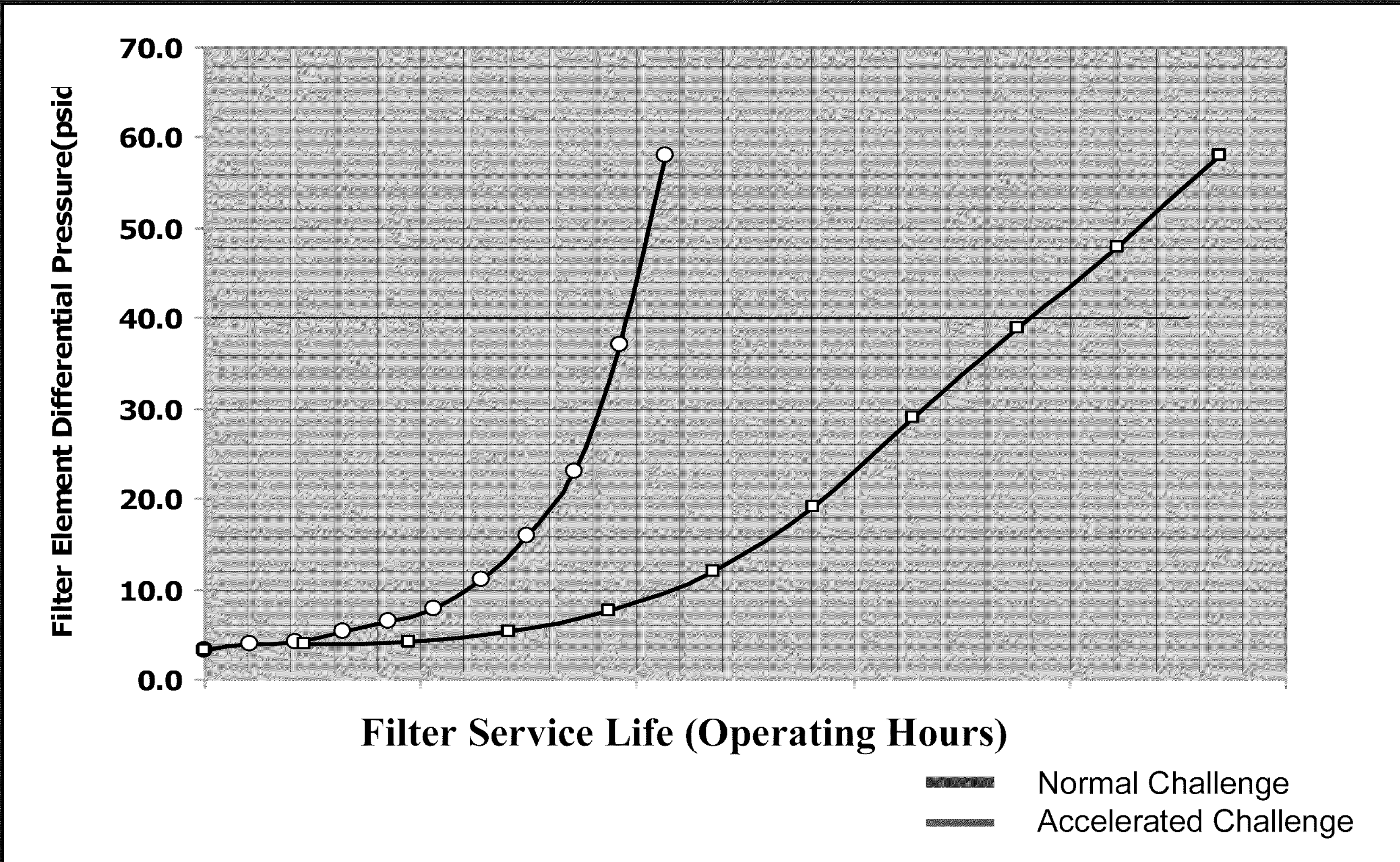
Pressure drop is caused by:

- Fluid viscosity
- Flow rate
- Contaminant ingression

Normalized data establishes filter element differential pressure as a function of contaminant loading.

258

Fluid System Health Monitoring



An abnormal rate of pressure drop rise is an early indication of a system problem

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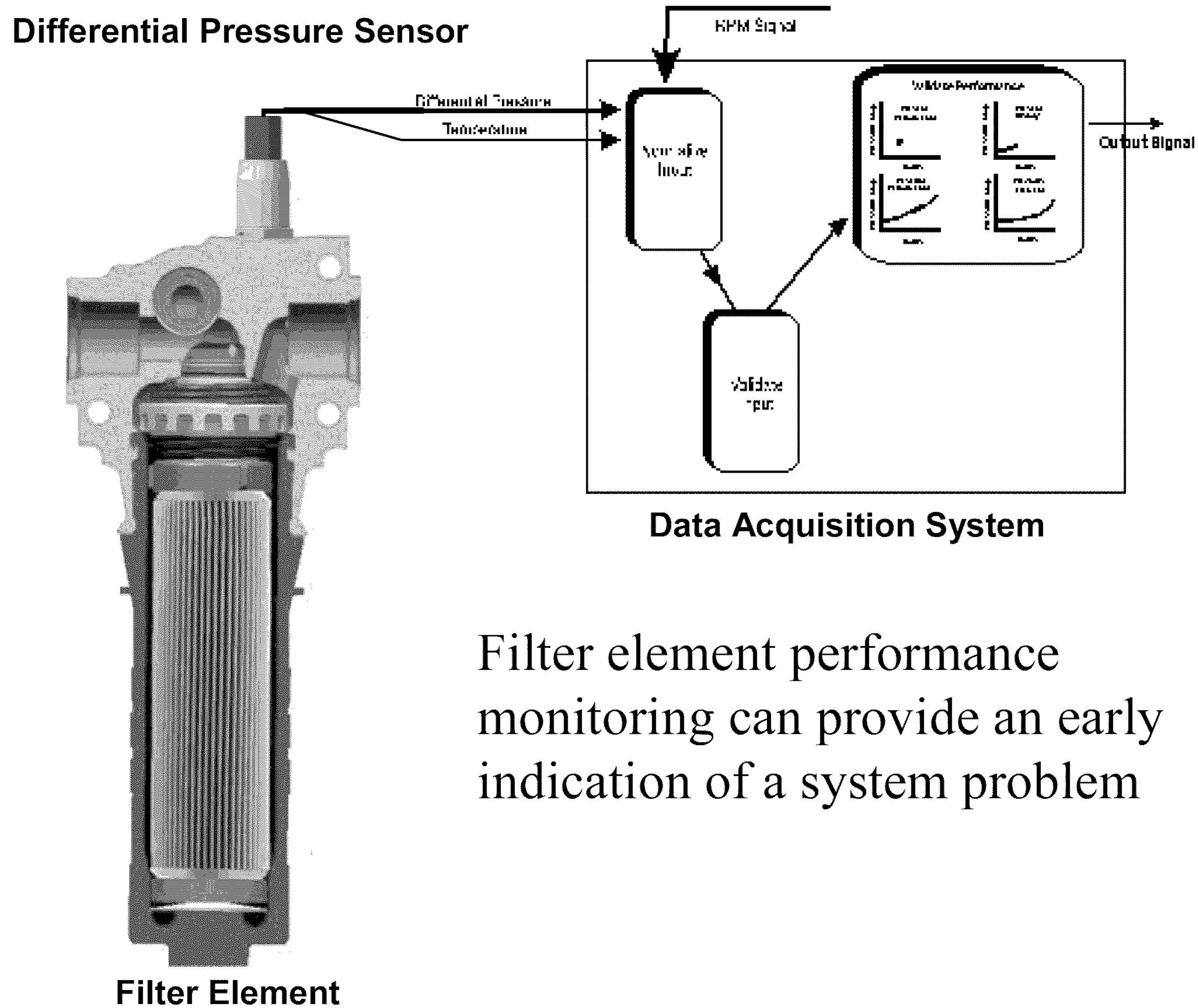
Fluid System Health Monitoring



Filter element performance monitoring can provide an early indication of a system problem

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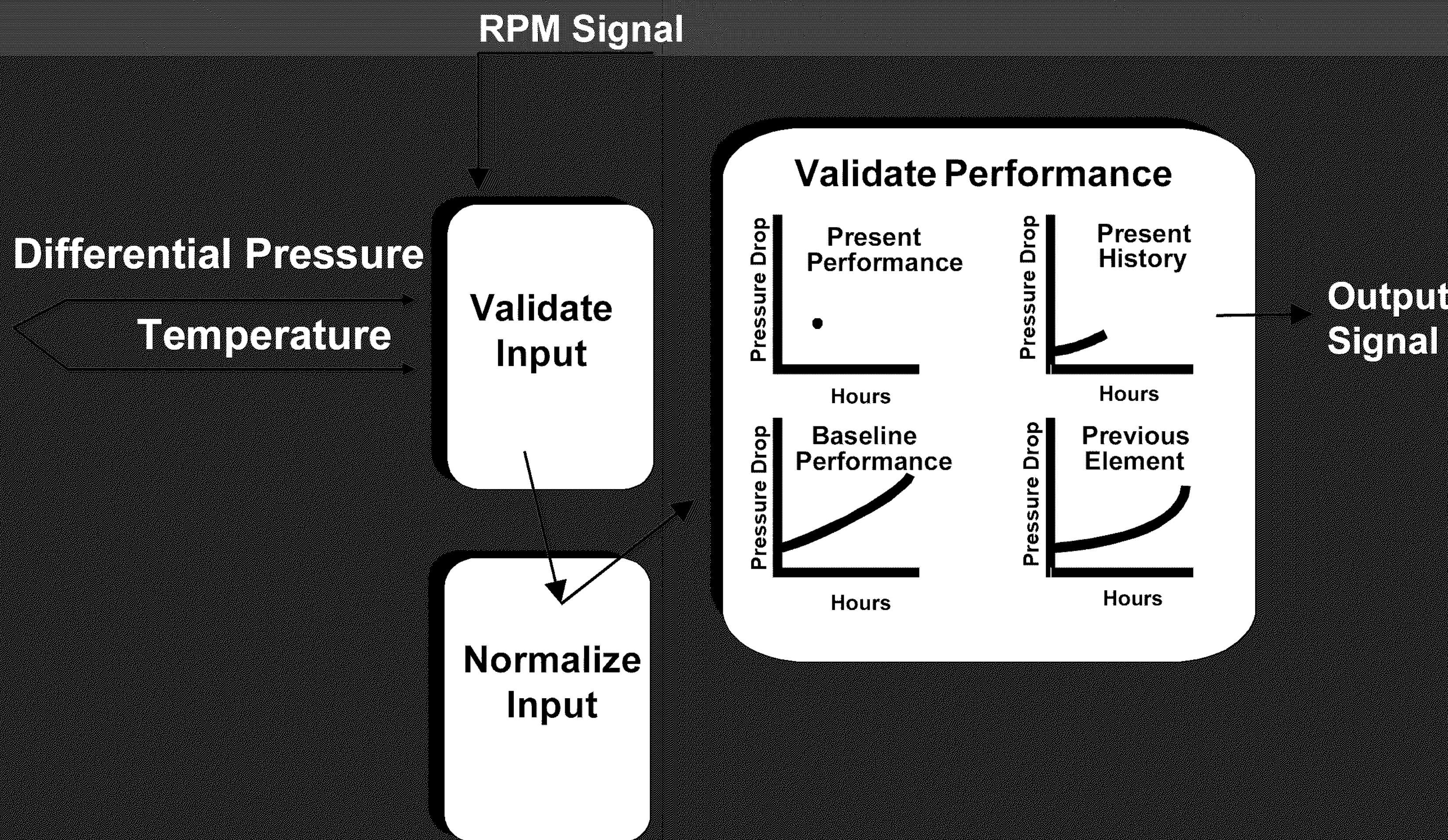
Fluid System Health Monitoring



261

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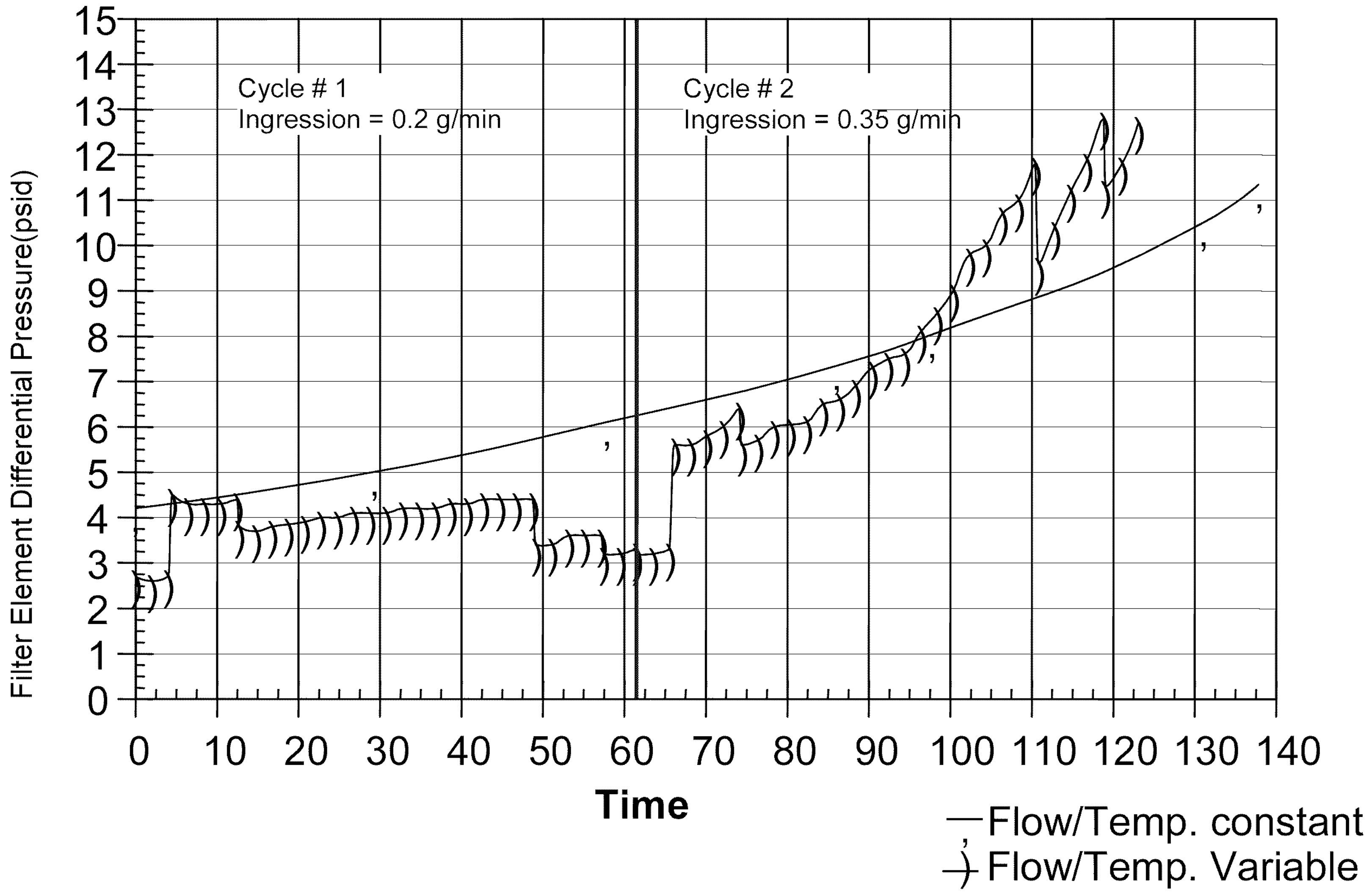
Fluid System Health Monitoring

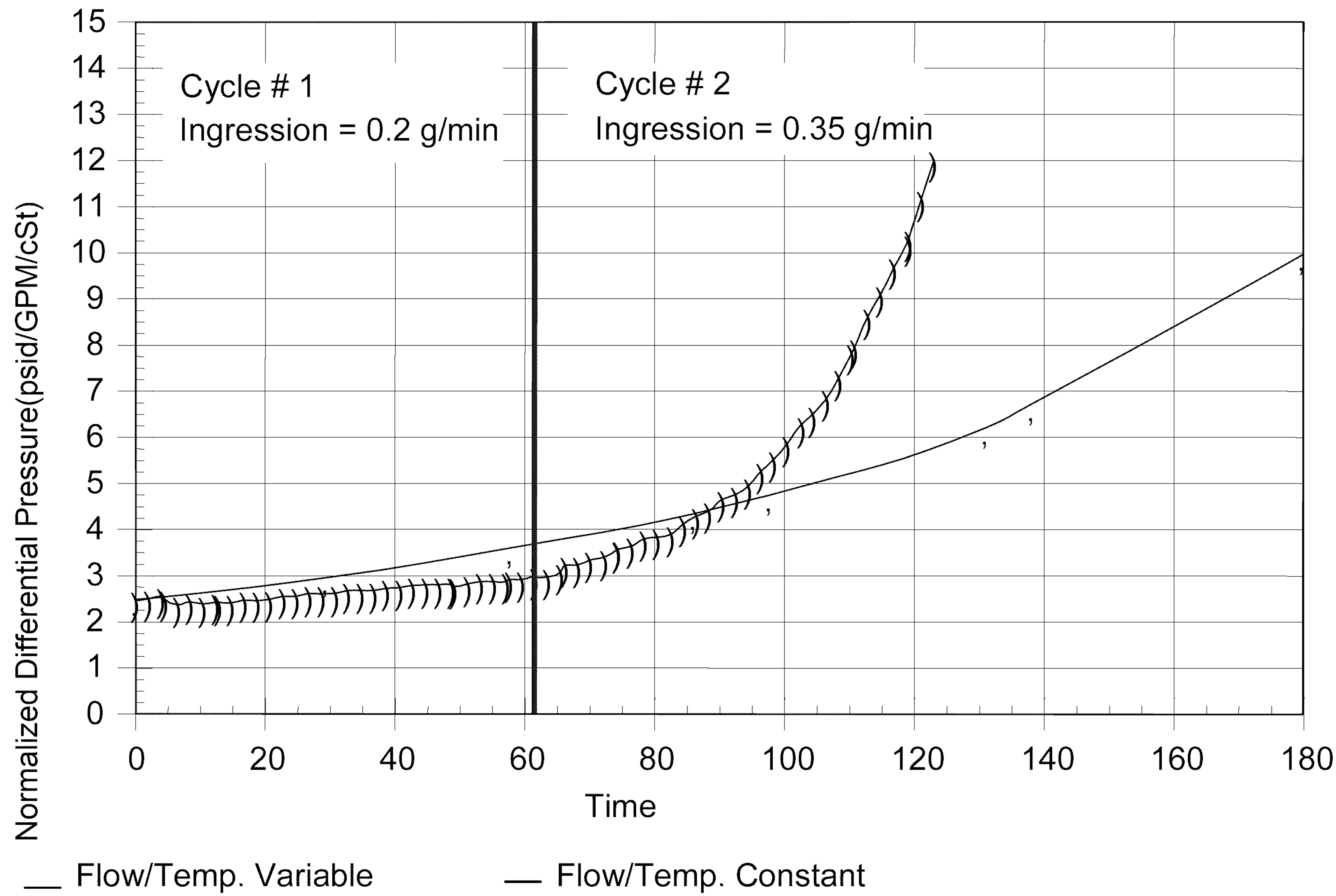
Filter Element Differential Pressure vs Operating Time



Filtration rating: Beta Ratio of 200 at 3 μm)

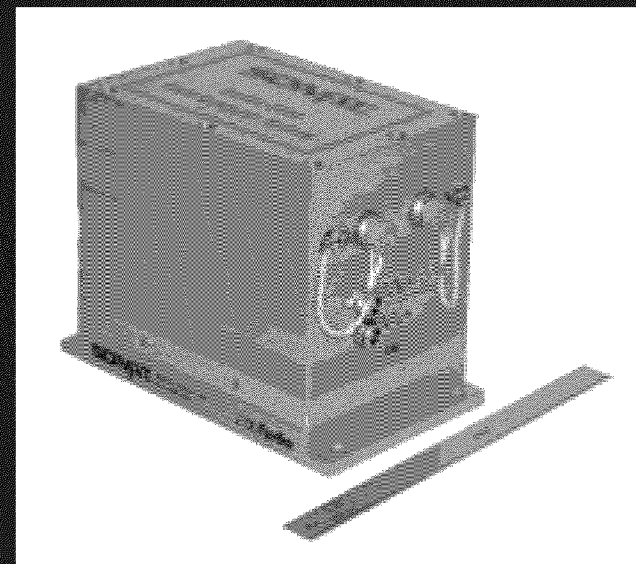
Fluid System Health Monitoring

Normalized Filter Element Differential Pressure



Fluid System Health Monitoring

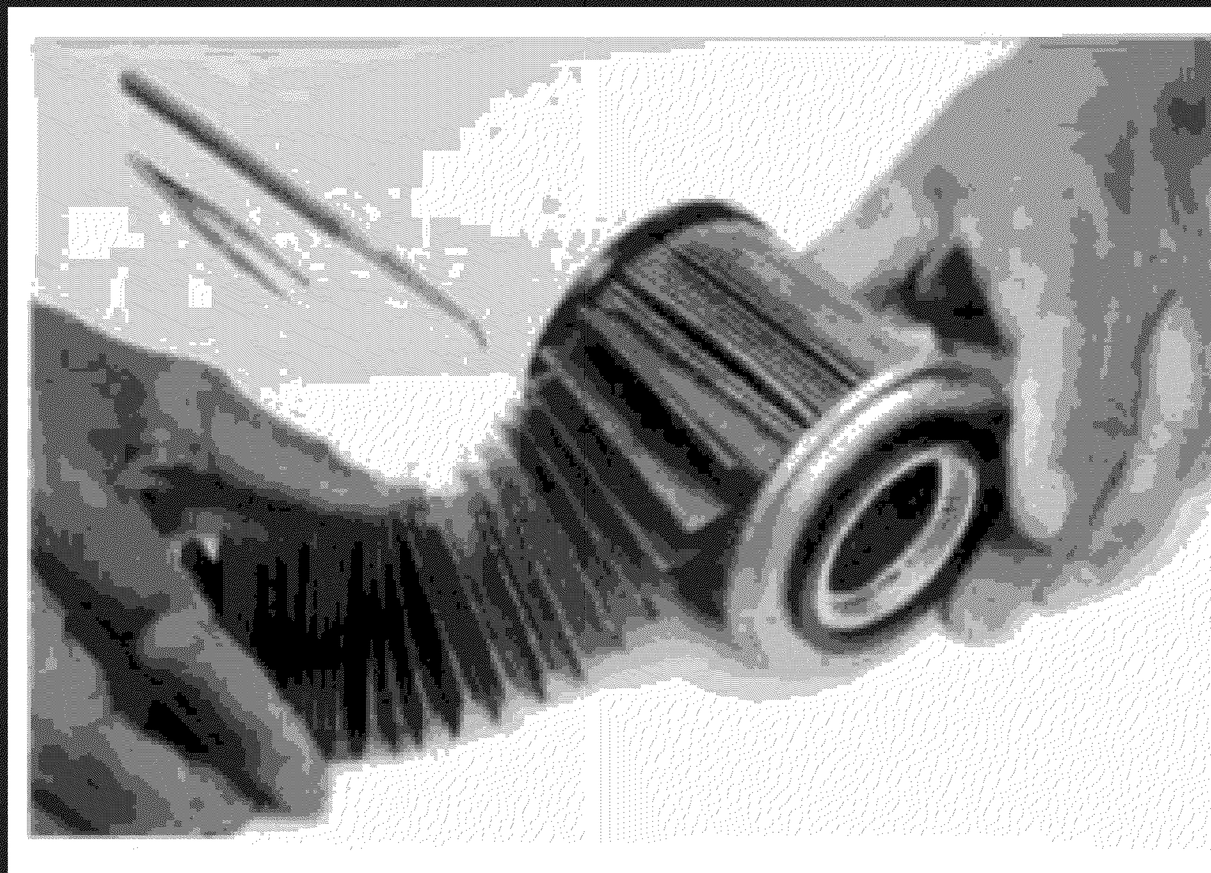
- Data Acquisition System output:
  - Filter element not installed
  - Remaining filter life
  - Change filter element
  - System problem
  - System in bypass
  - System over temperature



Fluid System Health Monitoring

- Identify system problem source
  - Abnormal particulate ingression indicates the existence of a system problem
  - Characterization of the captured debris can identify the problem source

Contaminants are Captured within a



Diagnostic Filter Elements

Fluid System Health Monitoring

Diagnostic Filters provide:

- Full flow contaminant removal
- Concentrated system debris of interest
- A very high signal to noise ratio
- A consistent debris capture process
- A tool for visual and elemental analysis

Characterization of captured debris can identify the source of a system problem

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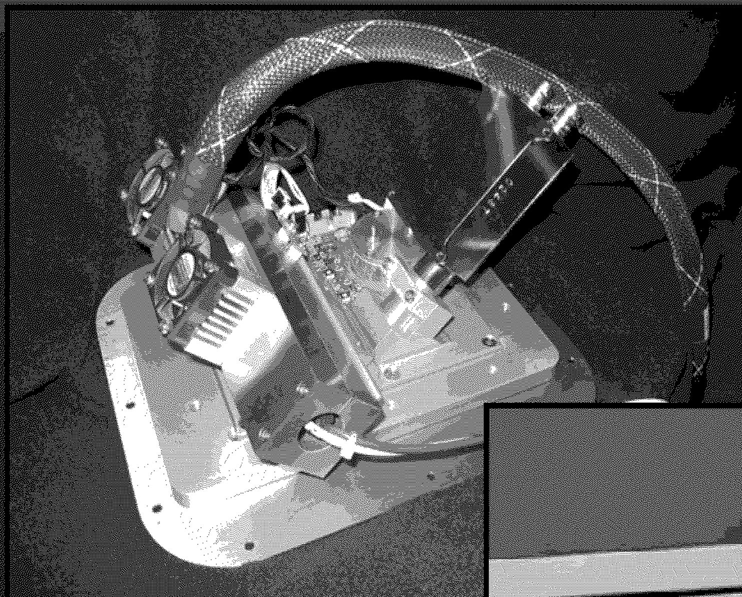
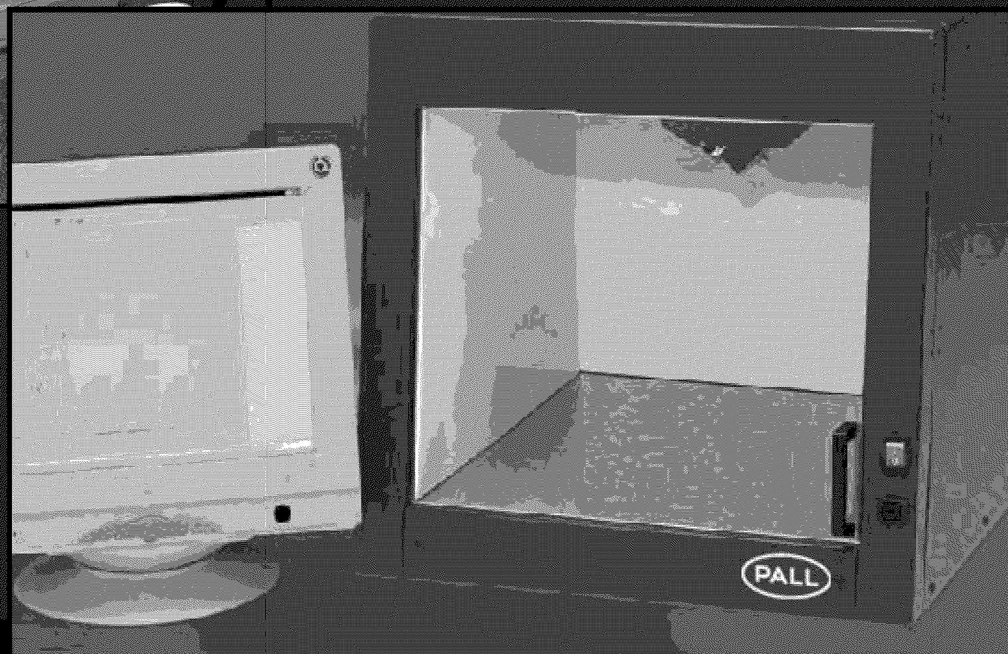
Fluid System Health Monitoring

Point of Filter Service XRF Contaminant Analyzer





Beta development unit

Fluid System Health Monitoring

Energy Dispersive
X-Ray Fluorescence spectroscopy:

- Portable, rugged, cost effective device for point of service use.
- Simple, fast and reliable analysis
- Non-destructive: permitting additional debris evaluation.
- Diagnostic filter evaluation increases information and eliminates variability of sample taking

Fluid System Health Monitoring

Energy Dispersive
X-Ray Fluorescence spectroscopy:

- Supports health monitoring and system trending.
- Provides quantitative information on the key chemical elements of interest.
- Expert system translates XRF output
- Allows for decision making at the operating level

Fluid System Health Monitoring

Summary:

- Ease of system incorporation
- Advanced notification of fluid system problems - schedule action
- Minimization of collateral system damage
- Full flow monitoring of system fluids
- Increased signal to noise ratio
- Identification of problem source
- Change system performance limits without changing hardware
- Reduce development & operating costs

ELIMINATION OF BARIUM CONTAINING FLUIDS IN DoD AIRCRAFT SYSTEMS

Lois Gschwender

Shashi Sharma

AFRL/MLBT

June 2004

ELIMINATION OF BARIUM CONTAINING FLUIDS IN DoD AIRCRAFT SYSTEMS

Outline

- The problem (Lois)
- Background
- Program matrix
- Results
  - Jar tests
  - Pump tests (Shashi)
- Summary (Lois)

The Problem

- DoD has traditionally used fluids containing barium dinonylnaphthalene sulfonate (BSN) for component storage.
  - Spent fluid is a hazardous waste
  - Documented problems of operational aircraft with BSN contamination
    - Army helicopters
    - Navy F-18s
    - Air Force T-38
  - Logistics/ footprint

The Problem

- T.O. 42B2-1-3 formerly described storage and shipping with rust inhibited fluid and then flushing and draining with the operational fluid prior to use.
- Some parts cannot have all of the rust inhibited fluid drained.

Background - Definition of Fluids

- The rust inhibited fluids contain ~3% BSN (1500 ppm Ba). Stability $\leq 225^{o}F$.
- EPA limit is 100 mg/l (120 ppm) water soluble Ba for hazardous disposal (EPA Handbook CFR, 261.24)

Base stock	Non-inhibited	Rust inhibited
Mineral oil	MIL-H-5606	MIL-PRF-6083
PAO oil	MIL-PRF-83282	MIL-H-46170

Background

- Aircraft components were stored with 4 different fluids at the start of program *
  - MIL-H-5606: B1B, C-130, C-135, E-3, E-4, E-6, F-5, P3C, U2R
  - MIL-PRF-83282: F-110 (F-16, actuator), F404, H60, H64, S60
  - MIL-PRF-6083: C-5A/B, F-117, F16
  - MIL-H-46170: AV8, C17, S3A, F15, E2C, F18, H53, H60, S60, V22

* Information from Parker Aerospace

Other reasons to change

- No documented reason for using inhibited fluid
- Component inventory going down - short shelf time for components
- Logistics - two fewer fluids in AF inventory
  - "Footprint" reduction
- Cost savings - charges from component suppliers and overhaulers

Hypothesis

Operational fluids work fine as component storage fluids

No documented part corrosion with operational fluids

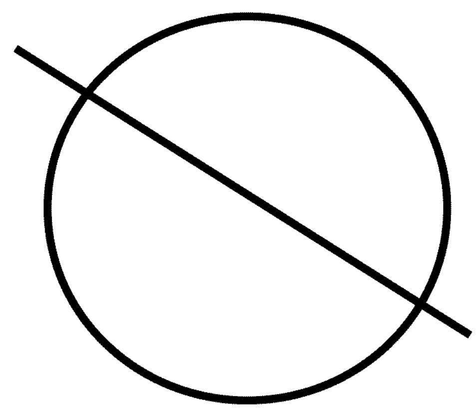
Laboratory tests indicated synthetic fluids more corrosion resistant than MIL-PRF-5606

AF Suggestion - 1995

- F-22 will not use rust inhibited fluid in component/armament for less than one year storage
- Resistance in AF to eliminate storage fluid across the board
  - Concern about potential corrosion problems
  - *No documented storage studies*

Program

- Needed well planned storage program to validate hypothesis
  - Pollution Prevention program proposed and funded, FY00 to FY04

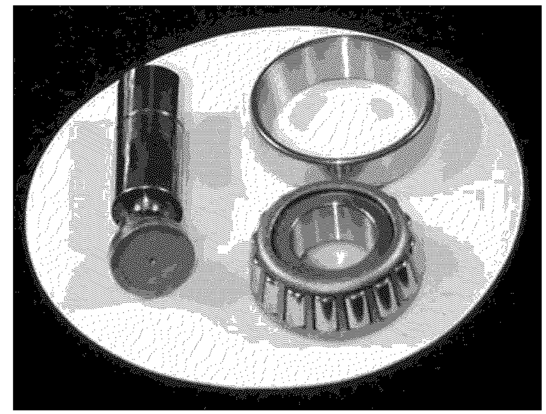


Program Test Matrix

- Queried MAJCOMs: HQ AMC, AFSOC/LG; SPOs, ASC, SSMs about test protocol
  - Real time storage, not heated to accelerate
  - Both rust inhibited and operational fluids
  - Submerged and drained parts
  - As received and water added to fluid
  - Room temperature and humidity monitoring
  - Component (pump) test after storage
- Two part program developed

Program Test Matrix, Part I, Jars

- Selected corrosion- prone, 52100 steel tapered bearings - Timken Bearing Co.- and used F-16 pump pistons in jar storage
- Submerged parts
  - Two water levels
    - MIL-PRF-5606, 83282 and –87257 fluids, 100 & 350 ppm water
    - MIL-PRF-6083 and -46170 fluids, 220 and 400 ppm water
- Dip & drain parts
  - Higher water level only
  - Parts dipped, drained, then put into jars



Program Test Matrix, Part I

- Jar tests set up April 2000
  - Visual observations monthly
  - Jar with specific test conditions (fluid and water 200/400 ppm level) off yearly for three years
  - Dip and drain jars also observed

Program Test Matrix, Part II

- 3 year pump storage begun June and July 2000
- F-16 EPU pumps purchased for storage and then pump testing after storage
- Three fluids in stored pumps: MIL-PRF-83282, MIL-PRF-87257 and MIL-PRF-46170
- Water added to fluids, 300 ppm
- Constant measurement of temperature and humidity
- Post test examination, photography and analysis, as needed
- Pump tests conducted on certain pumps at 3 years

Results, Jar Tests

PART I JAR TEST RESULTS

		Year		
Operational Fluids		1	2	3
MIL-PRF-				
83282				
87257				
5606				
Storage Fluids				
MIL-PRF-				
46170				
	Submerged			
	Dip & Drain			
6083				

Green = No change

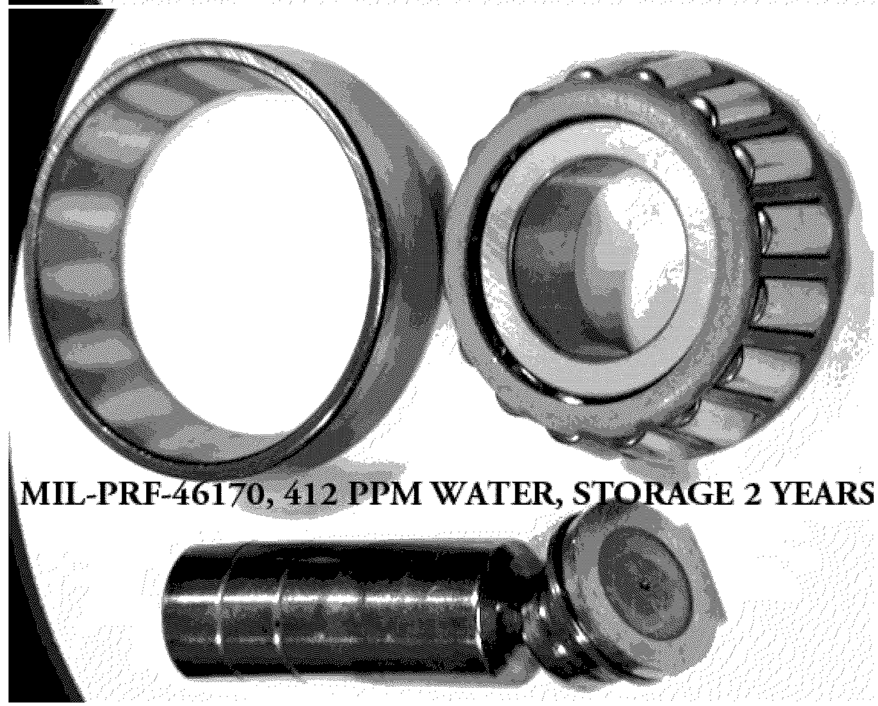
Yellow = Slight stain

Red = Stain


MIL-PRF-83282, 352 PPM WATER, STORAGE 2 YRS


MIL-PRF-46170, 215PPM WATER, STORAGE 2 YEARS


MIL-PRF-46170, 412 PPM WATER, DIP&DRAIN 2 YRS

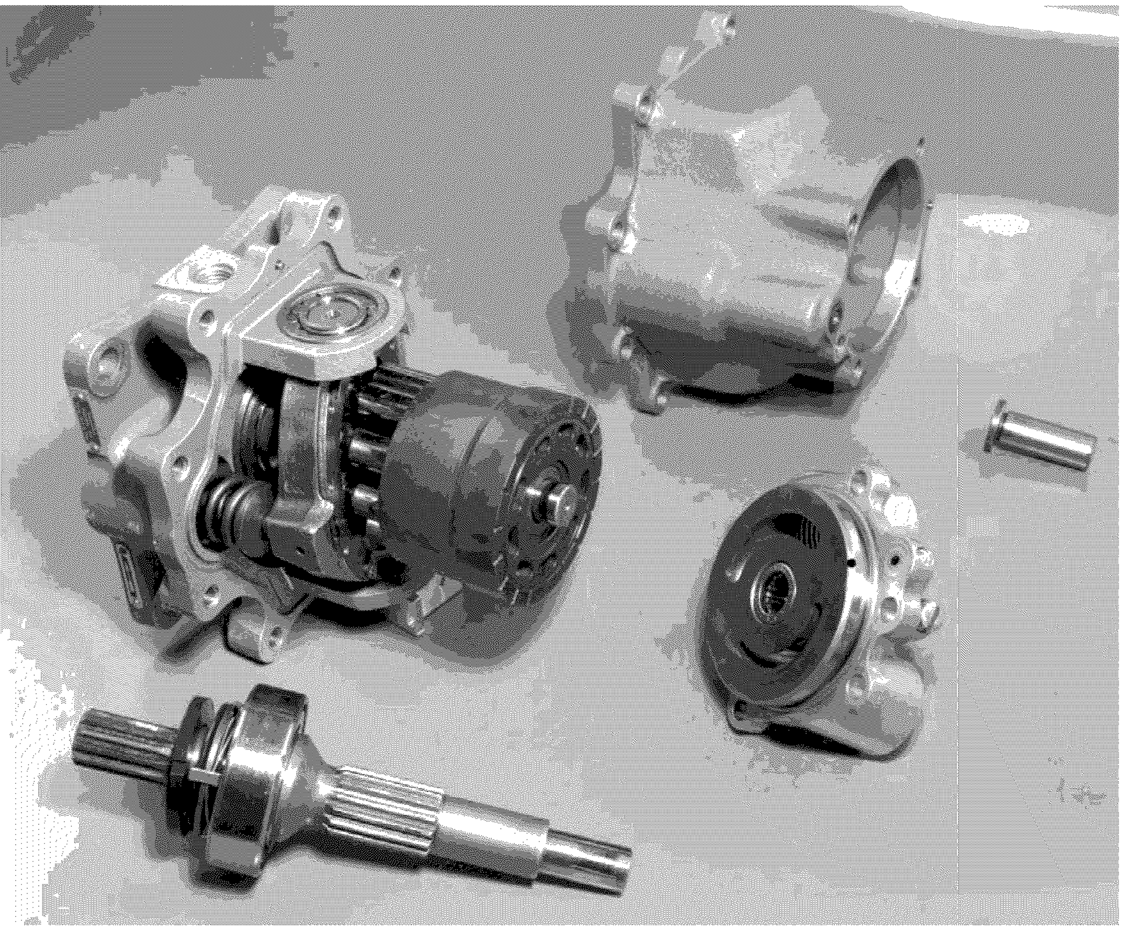

MIL-PRF-46170, 412 PPM WATER, STORAGE 2 YEARS

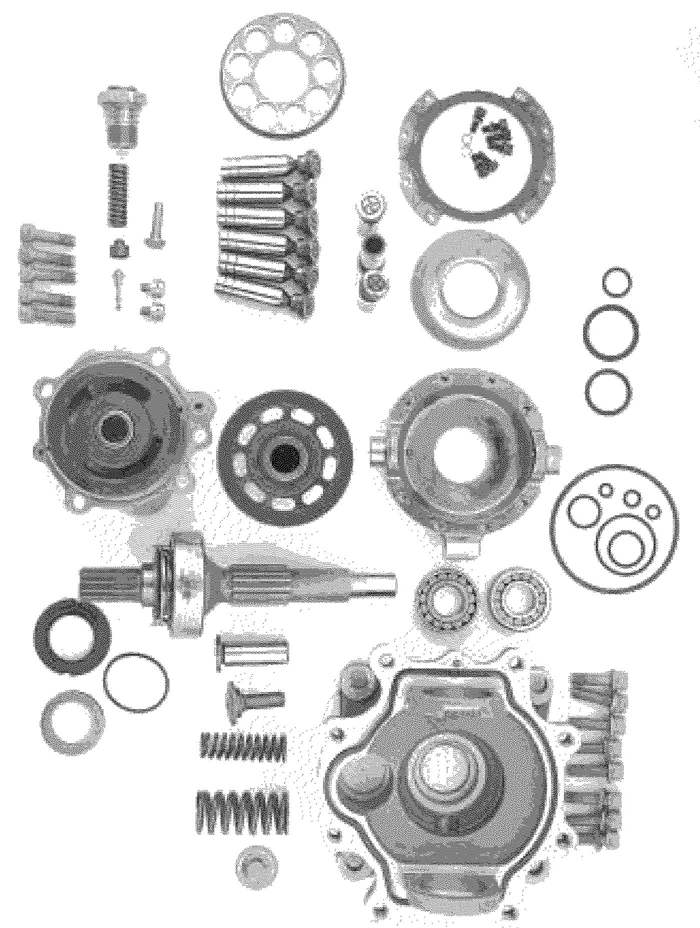
Jar Test Results Summary

- Jar tests with
  - Operational fluid – no changes
  - MIL-PRF-46170 – staining
  - MIL-PRF-6083 – no changes

Results, Pump Tests
(Shashi)

F-16 EPU pump, Eaton (Vickers) PV3-075-15

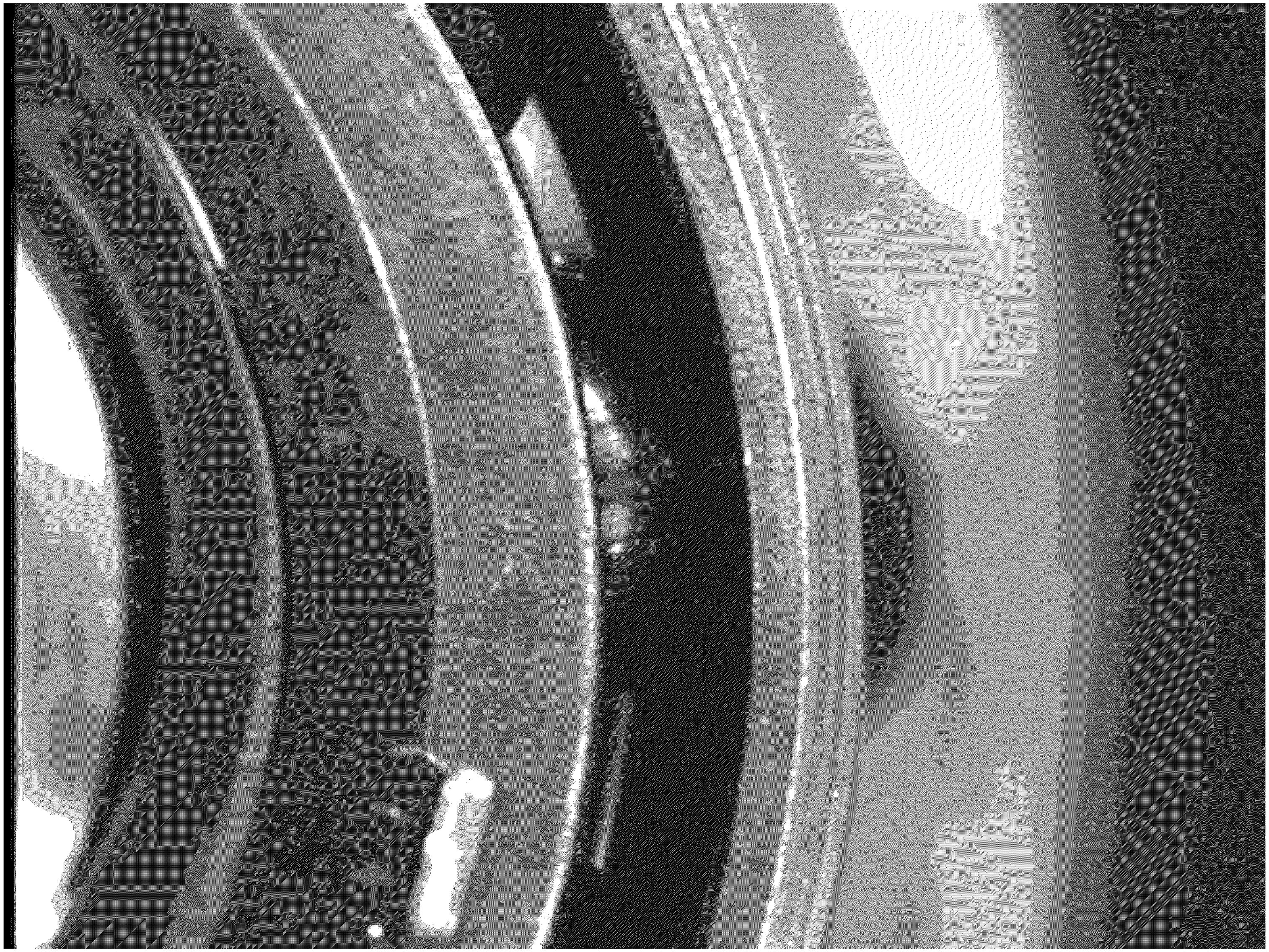




Part II Pump Storage Results

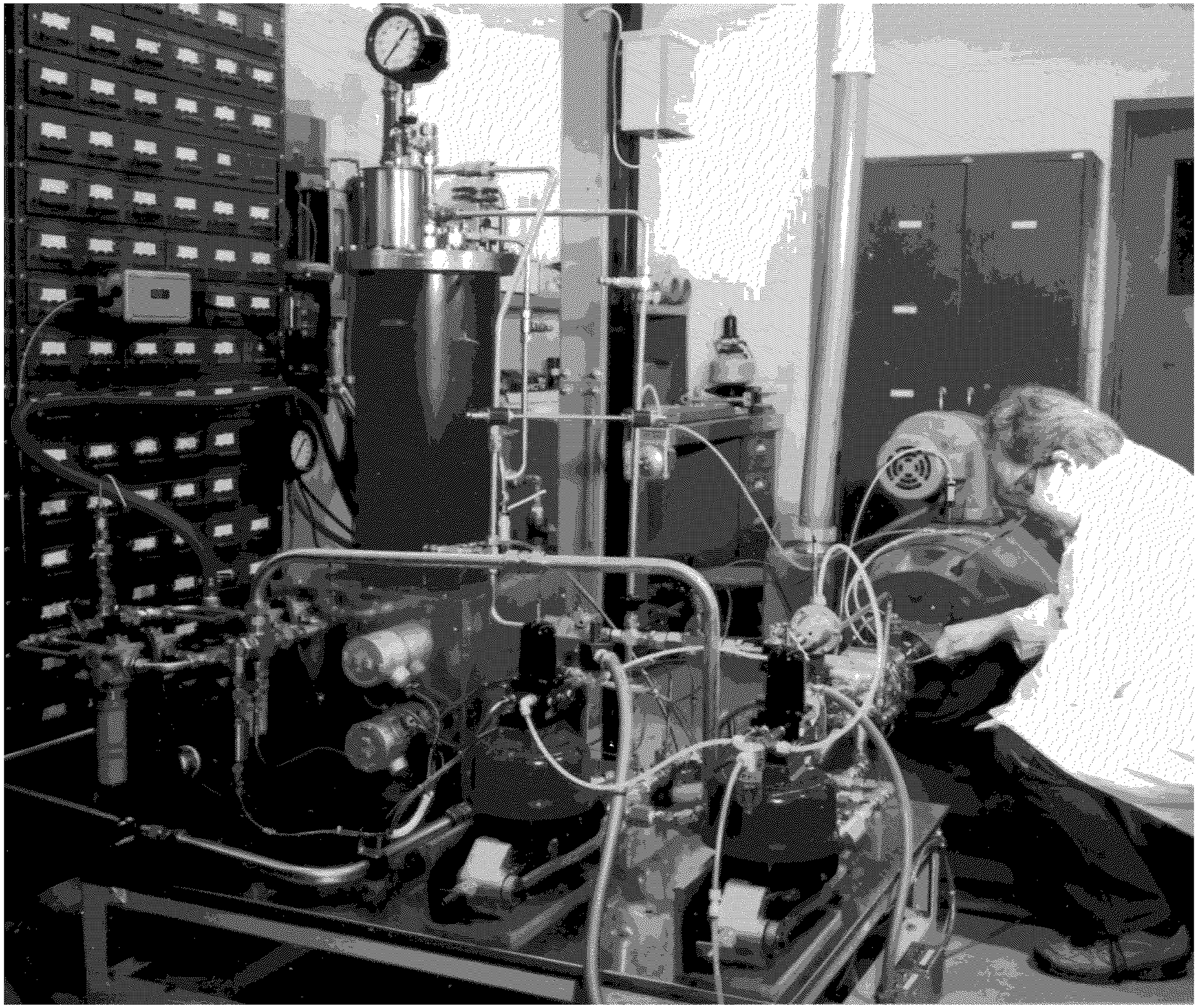
- 3 year pump storage begun June and July 2000 (300ppm water added)
  - Yearly inspection of MIL-PRF-83282 and MIL-PRF-87257 filled pumps - **no changes**
  - Yearly inspection of MIL-PRF-46170 filled pump - main bearing resisted turning, discoloration of metal, gel observed

MIL-PRF-46170 + 300 ppm water, 1 year storage



CHEMICAL REACTION MARKS ON SHAFT BEARING BALL

AFRL/MLBT Pump Test Stand



- 500 hours, 5000 rpm, 3000 psig, 255°F max fluid temp
- Flow cycled between 12 and 3 gpm every minute
- Periodic fluid samples

AFRL/MLBT Pump Test Stand

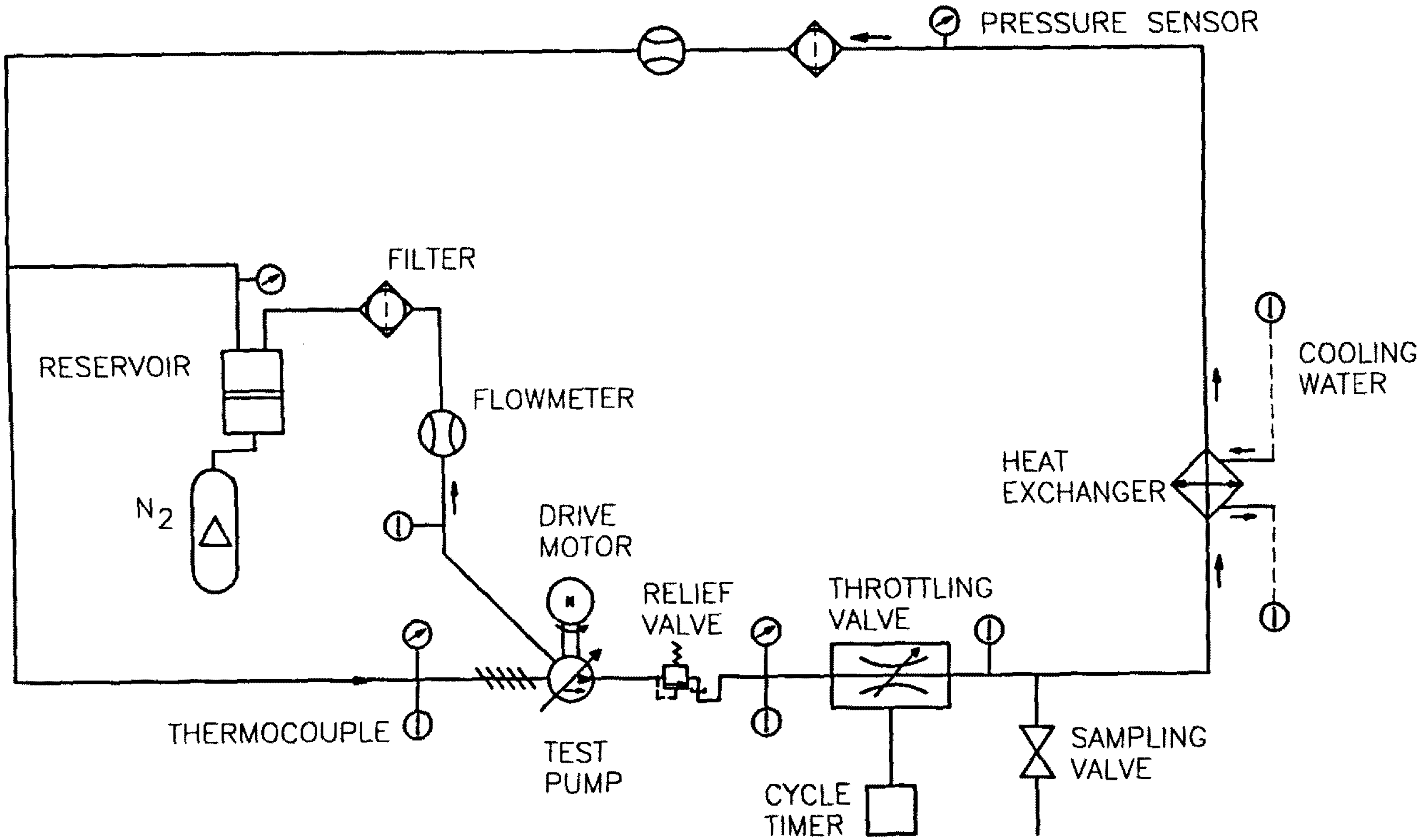


FIGURE 1: HYDRAULIC PUMP TEST CIRCUIT

Part II Pump Results

- Pumps stored with 300 ppm water, drained and filled with fresh fluid
- MIL-PRF-83282
  - Run 500 hours
  - Teardown inspection showed little wear
  - Parts shiny

Part II Pump Test Results

- MIL-PRF-87257
  - Piston defect caused pump failure at 275 hours
  - No rust or other indication of fluid related problem
- Two more PV3075-15 pumps put into storage with MIL-PRF-87257 for 3 years to assure pump failure was an anomaly
- Since no corrosion was observed with MIL-PRF-83282 and MIL-PRF-87257, MIL-PRF-46170 stored pump was not tested

Pump Test Results

- Pump tests with
  - MIL-PRF-83282
    - Storage – no change
    - Run 500 hrs, no corrosion
  - MIL-PRF-87257
    - Storage – no change
    - Run 275 hrs, piston failure, no corrosion
  - MIL-PRF-46170
    - Storage, staining, rough turning, gel formed
    - Not pump tested

Summary
(Lois)

Expected Payoff / Summary

- Using operational fluid for component storage will
  - Reduce hazardous waste stream
  - Eliminate source of operational problems
  - Consolidate number of fluids used
- Storage program assures users that parts won't rust on the shelf
- Save charges passed on by component suppliers and overhaulers

Post Script

- Final technical report being written on storage program
- Individual aircraft TO's are being changed
- Army and Navy also adopting use of operational fluid for component storage
- Specification for storage fluid MIL-PRF-46170, Type II has been cancelled

Lubricant Cleaning and Compatibility Studies for Chlorofluorocarbon and Hydrochlorofluorocarbon Solvent Replacements

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WORKING STOCK
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Outline

- Background
- Oxygen Wipe Solvents
  - Introduction
  - Solvents Evaluated
  - Static Immersion Cleaning Studies
    - Procedure, Equipment, Contaminants, Results,
  - Compatibility Studies
    - Procedure, Equipment, O-rings Used, Results
  - Conclusions
- Low Cost Precision Cleaning Solvents
  - Introduction
  - Program Guidelines
  - Solvents Evaluated
  - Static Immersion Cleaning Studies
    - Contaminants, Results
  - Ultrasonic Cleaning Studies
    - Procedure, Equipment
  - Compatibility Studies
    - Procedure, Equipment, O-rings Used, Results
  - Conclusions
- Overall Conclusions

Background

- Freon (1,1,2-triclorotrifluoroethane) widely used in military cleaning
  - versatile and effective
  - < $180/gal
  - easily recycled
  - fast drying
  - low toxicity
  - nonflammable
  - compatible with aircraft materials
  - various cleaning procedures

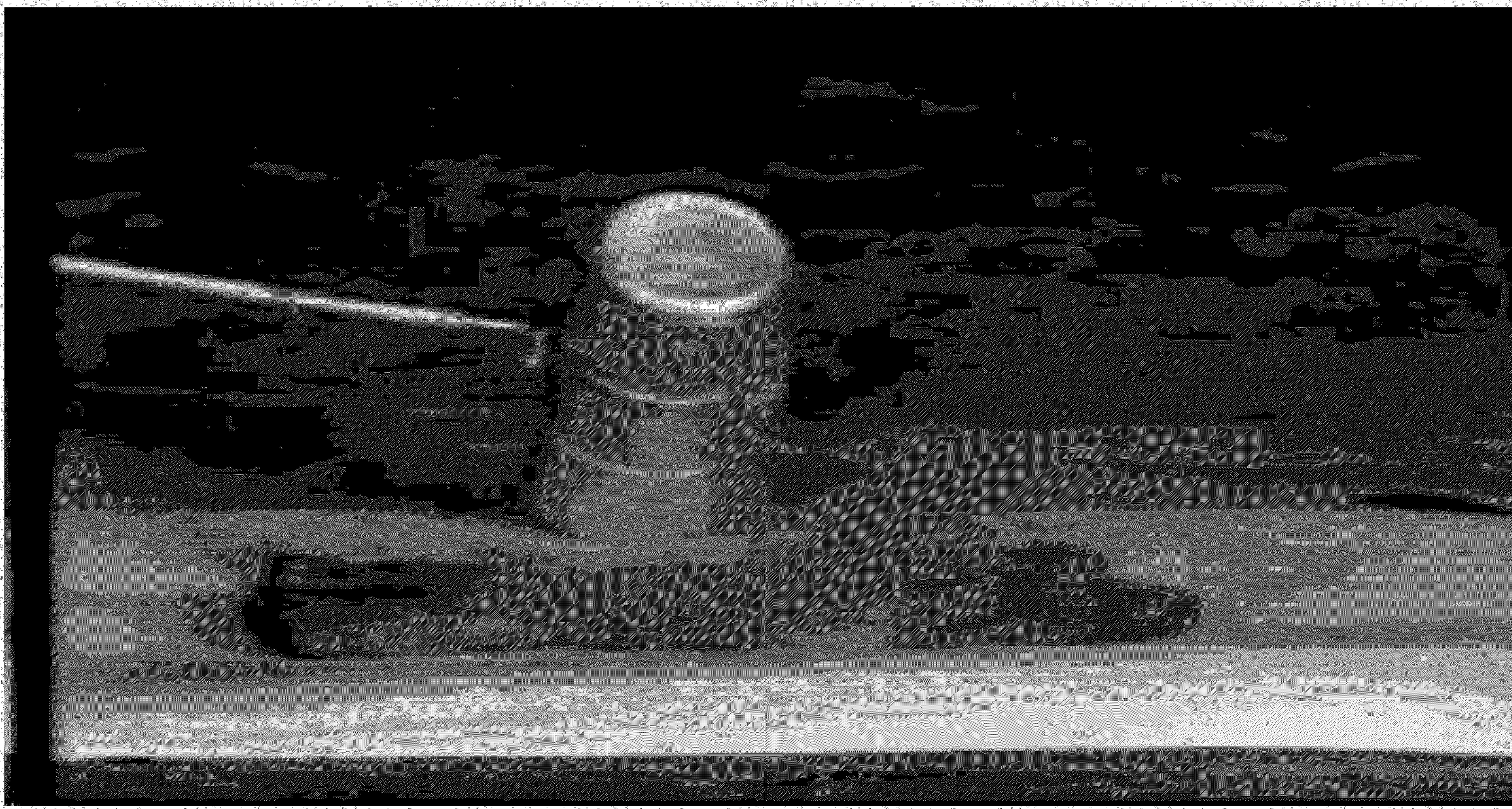
Background

- Freon production halted 1995 - Montreal Protocol & US Clean Air Act- Class I ODC
- Military stockpiles vanishing
- HCFC 141b (dichlorofluoroethane) and isopropanol substituted
  - Less effective - procedure changes
  - HCFC 141b - Class II ODC
  - Isopropanol - flammable

Introduction

- The production of Chlorofluorocarbon (CFC) and hydrochlorofluorocarbon(HCFC) solvents has been outlawed because they are ozone depleting
- CFC and HCFC solvents were used in LOX (Liquid Oxygen) and GOX (Gaseous Oxygen) cleaning applications.
- They were used for their excellent cleaning ability, good compatibility with the mechanical systems in which they were used, and they were very safe for the people using them.

LOX and GOX Compatibility Importance



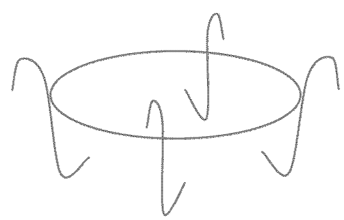
Solvents

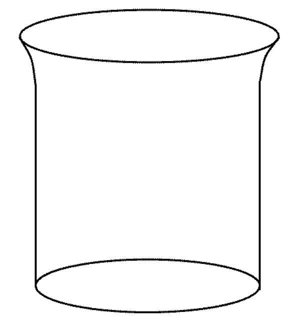
- Freon
- HFE 7100
- HFE 71IPA
- HFE 7200
- Ikon P
- Vertrel XF
- Vertrel X-P10
- AK 225-G

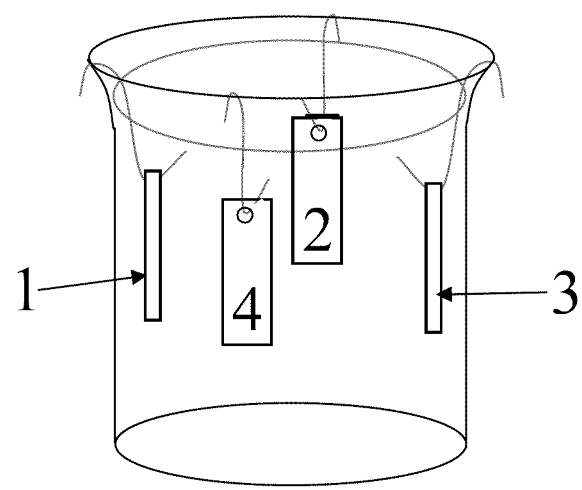
Procedure for Static Immersion Cleaning Study

- 1010 AISI Steel C.R.E.P. Coupons were cleaned by successive washings in Hexane and Acetone in an ultrasonic bath
- Coupons were dried in an oven for 10 minutes and cooled to room temperature
- Each coupon was engraved with a number
- Four coupons were weighed
- A small amount of contaminant was placed on each coupon and spread into a thin, even layer
- The coupons were weighed
- The coupons were hung on a wire stand inside a beaker
- Another beaker was filled with solvent
- The coupons on the wire stand were transferred to beaker containing solvent
- One Coupon was removed after 30, 60, 120, and 300 seconds
- The coupons were weighed

Experimental Set Up for Static Immersion Cleaning Tests


Wire Stand

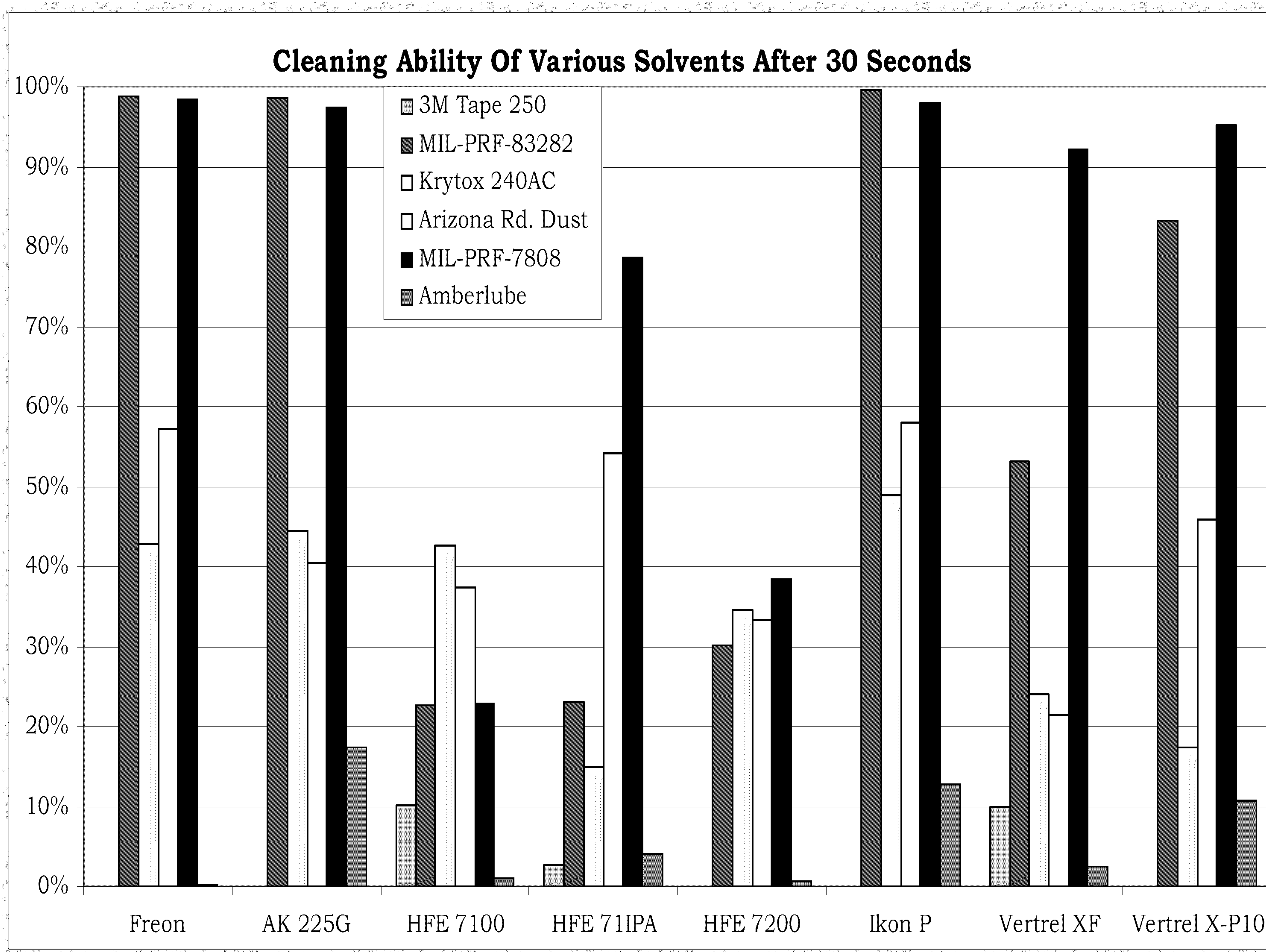

400 mL Beaker



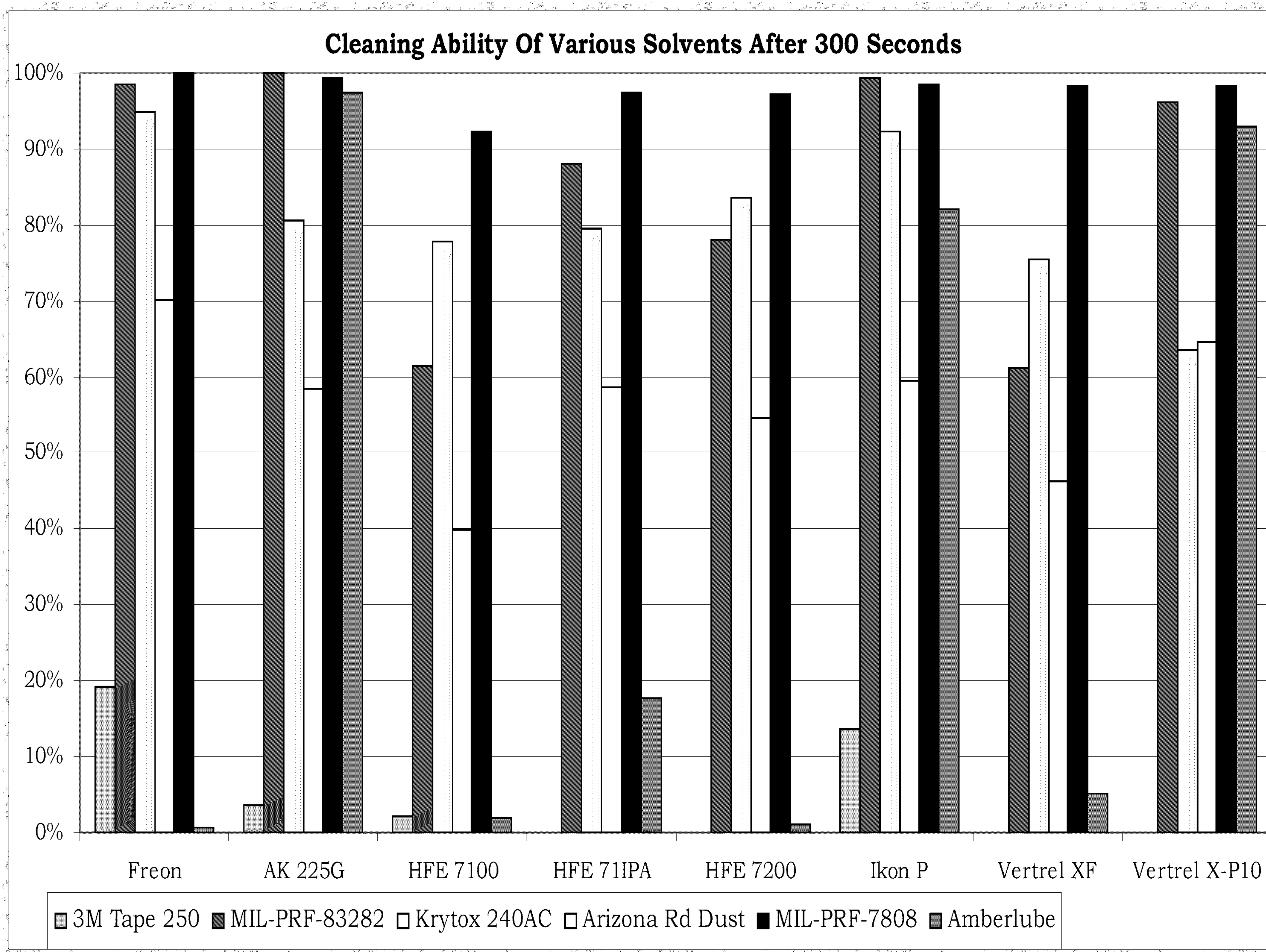
1 = 30 second trial
2 = 1 minute
3 = 2 minutes
4 = 5 minutes

Contaminants

- MIL-PRF-7808
- MIL-PRF-83282 (Hydraulic Fluid)
- MIL-PRF-27617 (Krytox 240AC)
- Arizona Road Dust on Krytox 240AC
- Duct Tape Residue (Aged @ 110^{o}C for 48Hrs)



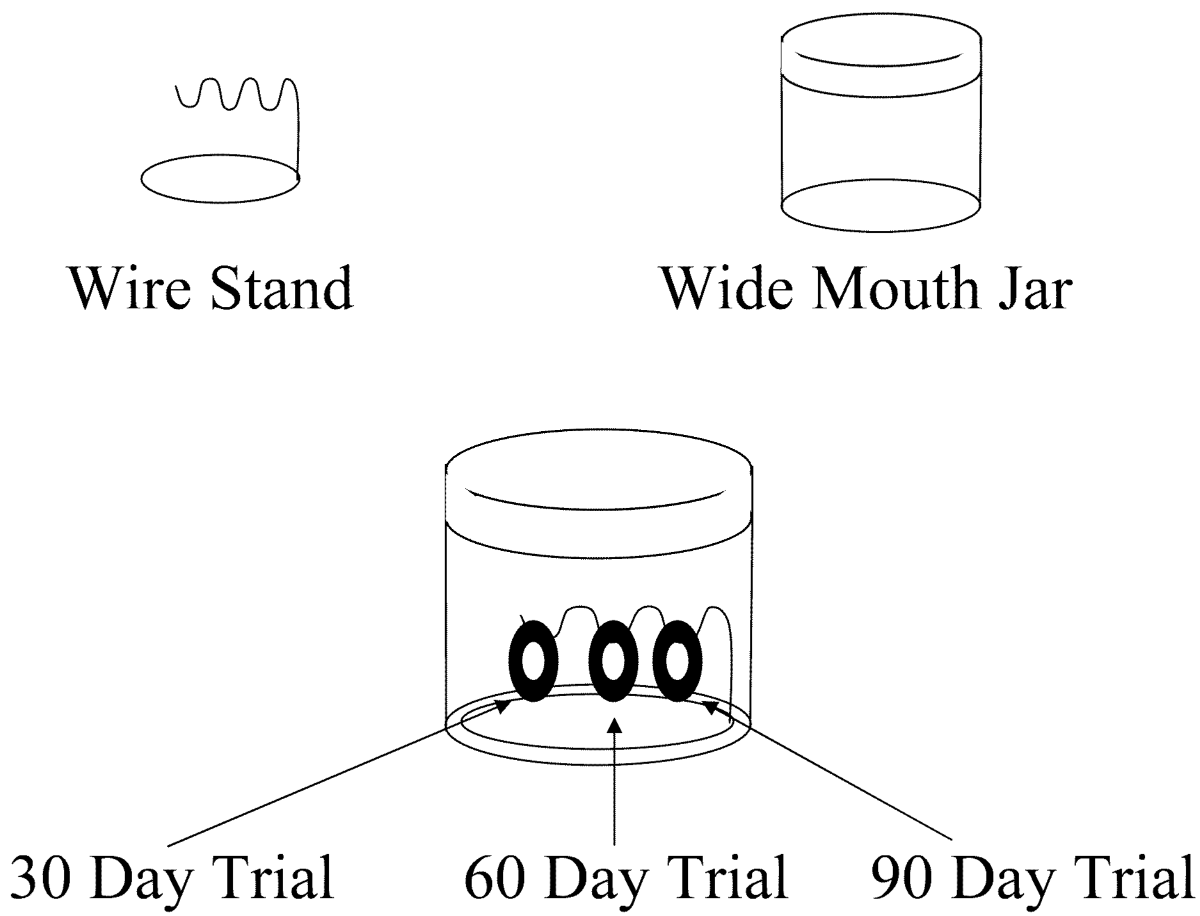
Cleaning Ability Of Various Solvents After 30 Seconds
3M Tape 250
MIL-PRF-83282
Krytox 240AC
Arizona Rd. Dust
MIL-PRF-7808
Amberlube
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Freon
AK 225G
HFE 7100
HFE 71IPA
HFE 7200
Ikon P
Vertrel XF
Vertrel X-P10


Cleaning Ability Of Various Solvents After 300 Seconds
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Freon
AK 225G
HFE 7100
HFE 71IPA
HFE 7200
Ikon P
Vertrel XF
Vertrel X-P10
3M Tape 250
MIL-PRF-83282
Krytox 240AC
Arizona Rd Dust
MIL-PRF-7808
Amberlube

Procedure for Compatibility Study

- Three of each type of o-ring were weighed in water and in air
- A hardness measurement was taken on the rubber seals
- The three o-rings of one type were placed on a wire stand in a jar
- Solvent was added
- The lid was tightly sealed on the jar
- The first o-ring was removed from the jar after 30 days. The second after 60, and the third after 90 days
- Immediately after being removed the o-rings were weighed in air and in water
- The rubber o-rings were also measured for hardness
- 3 to 5 days after removal from the jar, o-rings were weighed and hardness measured for the rubber o-rings a second time

Experimental Set-up for Compatibility Study



O-Ring Types

- Buna N
- TFE
- Kel F
- Viton A
- Silicone
- Neoprene

O_2 Wipe Solvent Program Conclusions

- Compatibility Study
  - None of the solvents had an unacceptable effect on any of the o-rings tested for any of the time periods
- Static Immersion Cleaning
  - **Ikon P** cleaned the highest percent of the contaminants next to Freon
  - **AK 225-G** was the next best
- Overall
  - TO 15-X-1 was changed to require the use of AK225-G

Introduction
Low Cost Precision Cleaning Solvents

- The CFC and HCFC solvents were also used in general military and laboratory cleaning
- A low cost replacement solvent was needed for these applications
- 32 Candidate Solvents and Aqueous Cleaners were picked for evaluation according to the following guidelines

Program Guidelines

- Cost of solvent a major driver
  - Cost limited to cost of Freon 113 when it was last available - $180/gallon
- Process changes acceptable
  - Ultrasonic assisted
  - Two step process
    - Clean and rinse
  - Accelerated drying

Solvents

- *Freon
- *Isopropyl Alcohol
- *HCFC 141b
- Abzol
- Ensolv
- DS-108
- AK-225
- OS-120
- Leksol
- Leksol AL
- Quik Solv

- EB-223
- Safecare Aircraft Cleaner
- Safecare MaxiSolv
- DMSO
- Brulin 1990GC
- Vertrel CCA
- SWROne
- Vigon US
- Armakleen M-Aero Cleaner
- Octagon OCC/NOC
- HFE-72DE

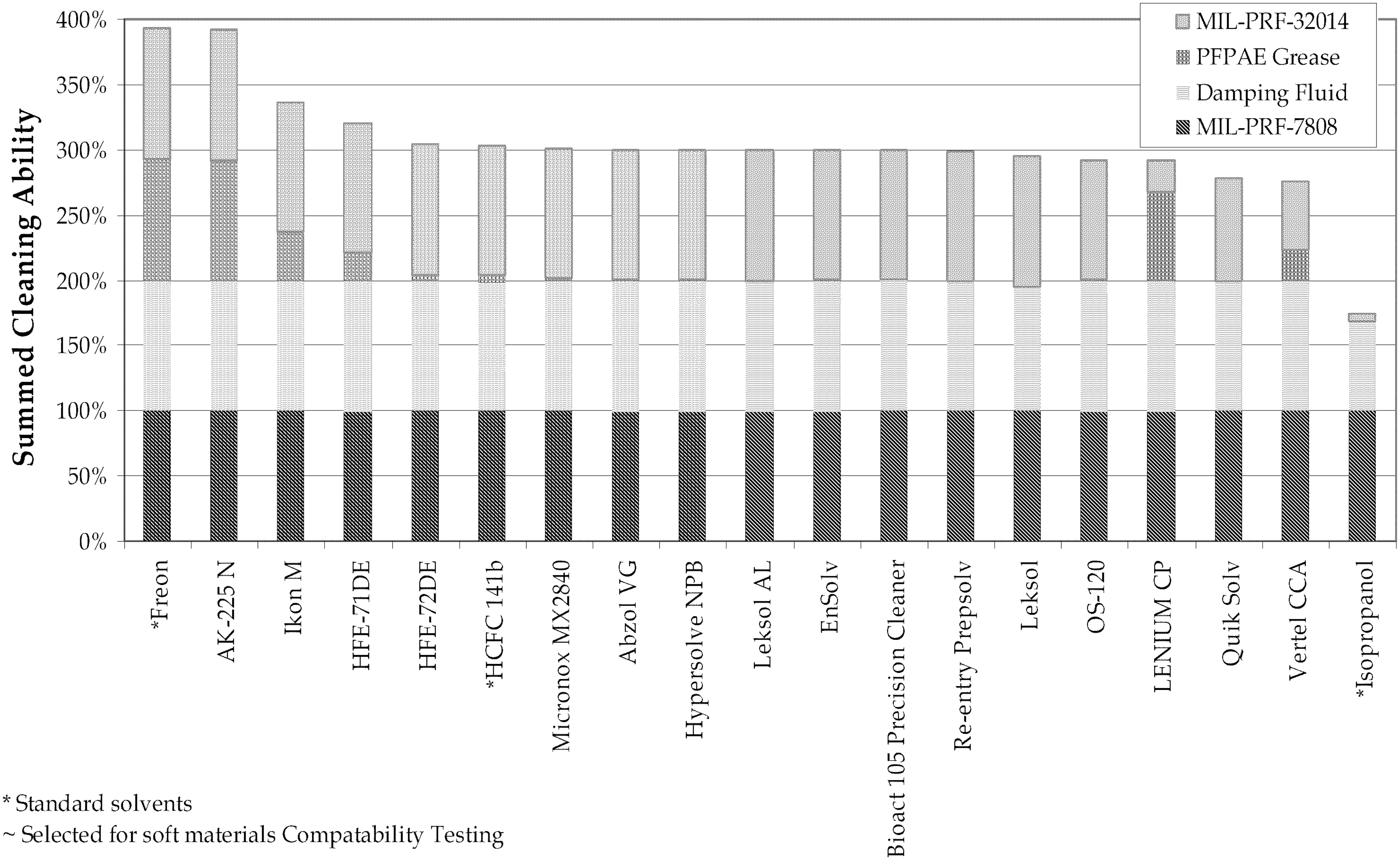
- Aquanox XNJ Plus
- Micronox MX2840
- Vertec Gold
- Lenium CP
- Re-Entry Prepsolv
- Bioact 105 Precision Cleaner
- ATTAR-C
- DOT 111/113
- BlueGold Industrial Cleaner
- Ikon M
- HFE-72DE
- ChemClean #2011

* - standard solvent

Contaminants

- MIL-PRF-7808
- MIL-PRF-27617 (Krytox 240AC)
- Damping Fluid (ELO 65-40)
- Hydrocarbon Grease (MLO 94-23)

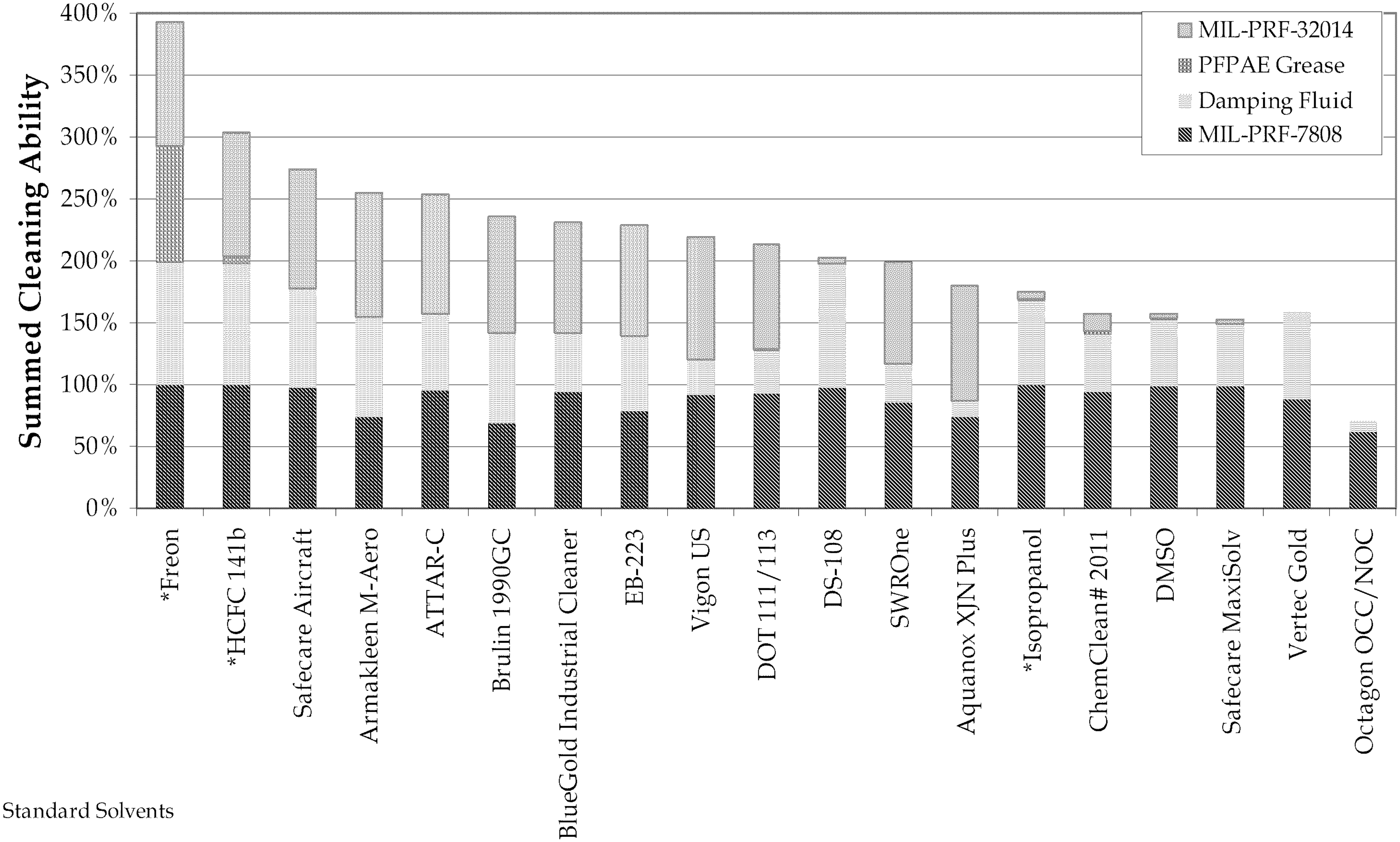
Cleaning Ability of Best 15 Solvents in 300 Seconds



* Standard solvents

~ Selected for soft materials Compatability Testing

Cleaning Ability of Remaining Solvents



* Standard Solvents

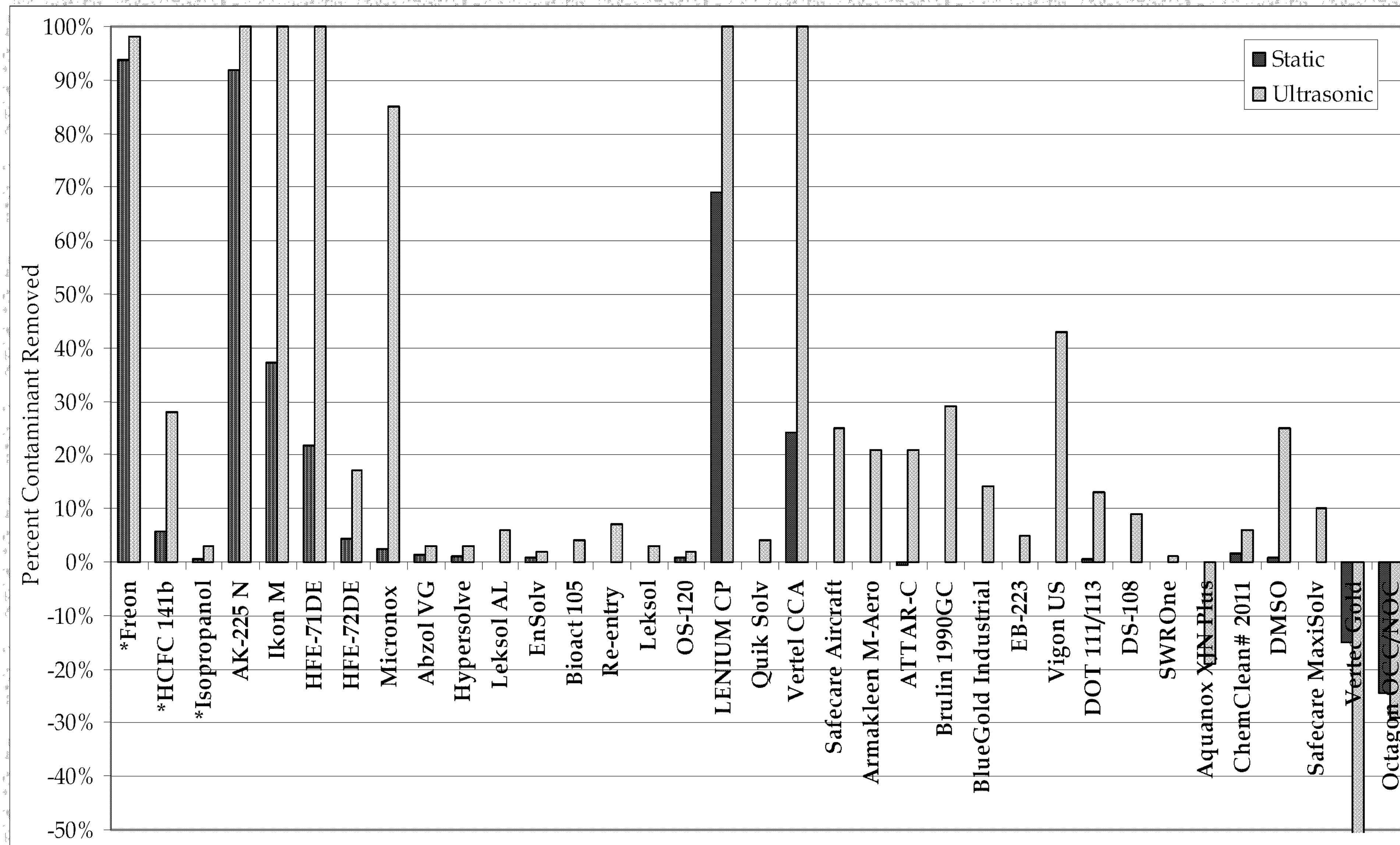
Results

- Fluorinated Solvents ranked 1 through 6, cleaning between 393% and 301% out of a possible 400%.
- Freon (CFC) and AK-225 (HCFC) ranked 1 and 2.
- The other fluorinated solvents ranked 3rd through 6th and 19th.
- All solvents comprised of n-Propylbromide cleaned between 294% and 300% out of a possible 400%.
- The nPB solvents ranked 7th through 10th, and 12th out of 34.
- Aqueous Cleaners, DMSO, IPA, Terpenes, and Ethyl Lactate cleaners did not perform well.

Ultrasonic Cleaning Study

- Certain solvent/soil combinations were chosen to be run in an ultrasonic cleaning study to see if running the cleaning procedure in an ultrasonic bath could make a cheaper solvent clean adequately.
- Any Solvent that did not remove at least 95% of a given contaminant within 5 minutes was run in an ultrasonic cleaning test.
- The ultrasonic cleaning test is the same as the static cleaning test except that the full beaker of solvent is placed in a running ultrasonic bath prior to placing the metals in the beaker.
- The most important results were found when cleaning PFPAE Grease.

Static and Ultrasonic Cleaning Ability to Clean Krytox Grease



Down Select for Compatibility Testing

The top 11 solvents by total cleaning ability, a sum of the individual cleaning abilities, were selected for further testing, the materials compatibility test.

- These solvents are: AK-225, Ikon M, HFE71DE, HFE-72DE, Micronox, Abzol, Hypersolv, Ensolv, Leksol AL, Bioact, and Re-Entry Prepsolv.
- Freon was also tested as a standard.

O-Ring Types

- Fluorosilicone
- Nitrile 25732
- Nitrile 83461
- Silicone 3340
- Silicone 6855
- Viton 83248

Compatibility Procedure

- For this program the o-rings were removed from the solvent after 2, 7, and 30 days rather than after 30, 60, and 90 days as was done in the wipe solvent program.

Results

- None of the solvents had an unacceptable effect on any of the o-rings tested for any of the time periods

Precision Cleaning Solvent Program Conclusions

- In the Compatibility Study none of the solvents exhibited unacceptable permanent damage to any of the o-rings.
- Highly halogenated, containing Cl, I or Br, solvents are more effective cleaners especially with PFPAE contamination
- The most effective solvent compared to Freon was HCFC 225, then Ikon M and HFE 1
- Aqueous cleaners did not perform well in these experiments
- Ultrasonic cleaning improved performance of most cleaners

Overall Conclusions

- Effective environmentally acceptable replacement solvents were developed for the banned chlorofluorocarbon solvents for both cleaning oxygen systems as well as precision cleaning applications.
- AK225-G was found to be a good replacement for banned solvents in O_2 cleaning applications. T.O. 15-X-1 was changed to require the use of AK225-G.
- Several low cost alternatives were found for precision cleaning applications: AK225, Ikon M, Micronox, Vertrel CCA, HFE71DE, HFE72DE, and Lenium CP.

Oxygen Sensor Development

SBIR Topic AF04-126

Oxygen Sensor Development

- Objective: Develop an on-line oxygen sensor to determine the oxygen content of the air above the fuel in aircraft fuel tanks

Oxygen Sensor Development

- Requirements
  - O_2 Content 9 to 12%
    - When O_2 content exceeds 12%, sensor sends signal to activate OBIGGS
    - When O_2 content gets down to 9%, sensor sends signal to de-activate OBIGGS
    - There could be a warning signal as the 12% and 9% limits are approached

Oxygen Sensor Development

- Requirements – cont'd
  - Temperature range –65^{o}F to +125^{o}F
  - Compatible with fuel and fuel vapors
    - Maintains operational capability after being wetted by fuel repeatedly
    - No ignition hazard
  - Reliable
  - Maintainable – No major maintenance prior to 2 years in service

Oxygen Sensor Development

- Requirements
  - Lightweight
  - Robust
    - Capable of withstanding shocks associated with landing
    - Insensitive to aircraft vibrations
  - Reliable

Oxygen Sensor Development

- Requirements
  - Small Size
  - Low cost
  - Compatible electrical requirements

Oxygen Sensor Development

- Phase I Exit Criteria
  - Working prototype demonstrate
    - Ability to sense O_2 concentrations of interest in the air above a simulated fuel tank (Proof of feasibility of technical approach)

Oxygen Sensor Development

- Phase II Exit Criteria
  - Complete development of sensor in final, flightworthy form
  - Demonstrate capability to meet all performance requirements
  - Demonstrate long term compatibility and operability after exposure to fuel and fuel vapors by accelerated testing
  - Deliver a full-scale, simple to operate working unit

Oxygen Sensor Development

Schedule

January 04	Phase I Proposals Due
February 04	46 Phase I Proposals Evaluated
April 04	5 Phase I Contract(s) Awarded
November 04	Phase II Proposal(s) Due
January 05	Phase II Proposal(s) Evaluated
April 05	Phase II Contract(s) Awarded
March 07	Phase II Contract Complete – Monitor Available for Air Force Testing/Validation
May 07	Phase III Required?

Oxygen Sensor Development

Status

Kickoff meetings have been held with all five Phase I contractors

Excellent involvement/interaction with SPO and PR

Good progress being demonstrated by all contractors

Due to proprietary nature of SBIR contracts, further details cannot be provided

Lubrication for Gas Turbine Engines

Presented at:
Military Aviation Fluids and Lubes Workshop

16 June 04

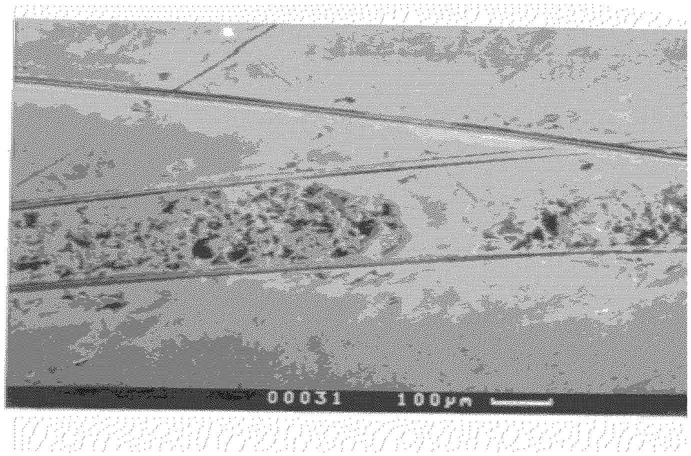
Nelson H Forster, PhD
Principal Engineer
Propulsion Directorate
Air Force Research Laboratory

Engine Performance

- Starting with the F119 engine, performance requirements started to exceed the capability of the Grade 3 oil (7808 J) introduced in the late 1970s
- Engine power density, fuel temperature, and the resulting oil temperature for Joint Strike Fighter has pushed this even further
- Grade 3 oil has been removed from the JSF program
- What are the attributes we need in a new oil?
  - Viscosity
  - Thermal stability
  - Compatibility/Performance with a new generation of component materials

Lubricant Can Affect Bearing Fatigue

Race scratches due to hard contaminant



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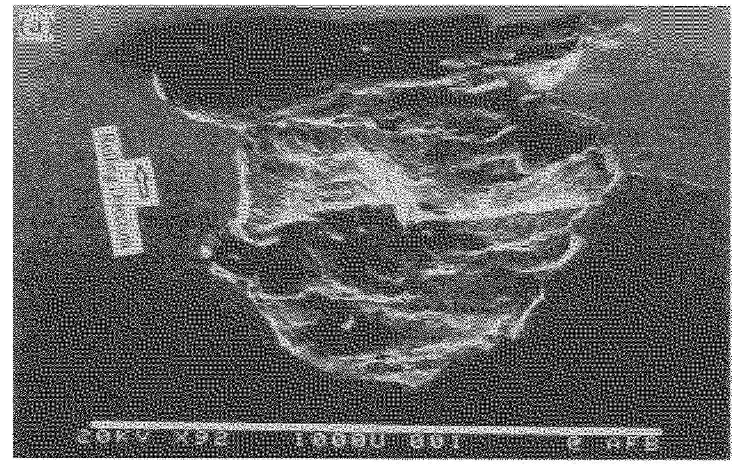
Fatigue Spall

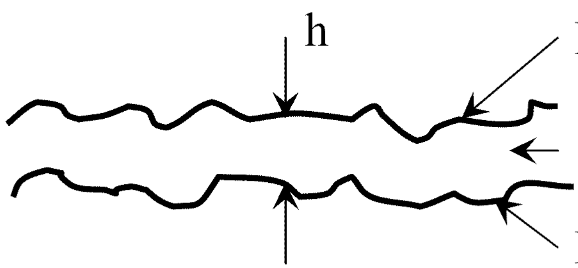


- Lubricant impacts the leading cause of bearing failure:
  - Viscosity → Film Thickness → Reduces stress around surface defects
- Oil Additives can have a positive or negative effect:
  - Positive - Boundary Additives can add to the lubricant film
  - Negative - Aggressive chemistry can promote micro-spalling

3

Modes of Lubrication

Full Elastohydrodynamic Lubricant (EHL) Film



Bearing Contact 1000X Magnification

$$\lambda = \frac{h}{[\sigma_1{}^2 + \sigma_2{}^2]^{1/2}} = \frac{\text{Lubricant Film}}{\text{Average Roughness}}$$

$\lambda > 2$; Long Life Bearing

Mixed Mode Lubrication

Some Metal-to-Metal Contact at Asperities

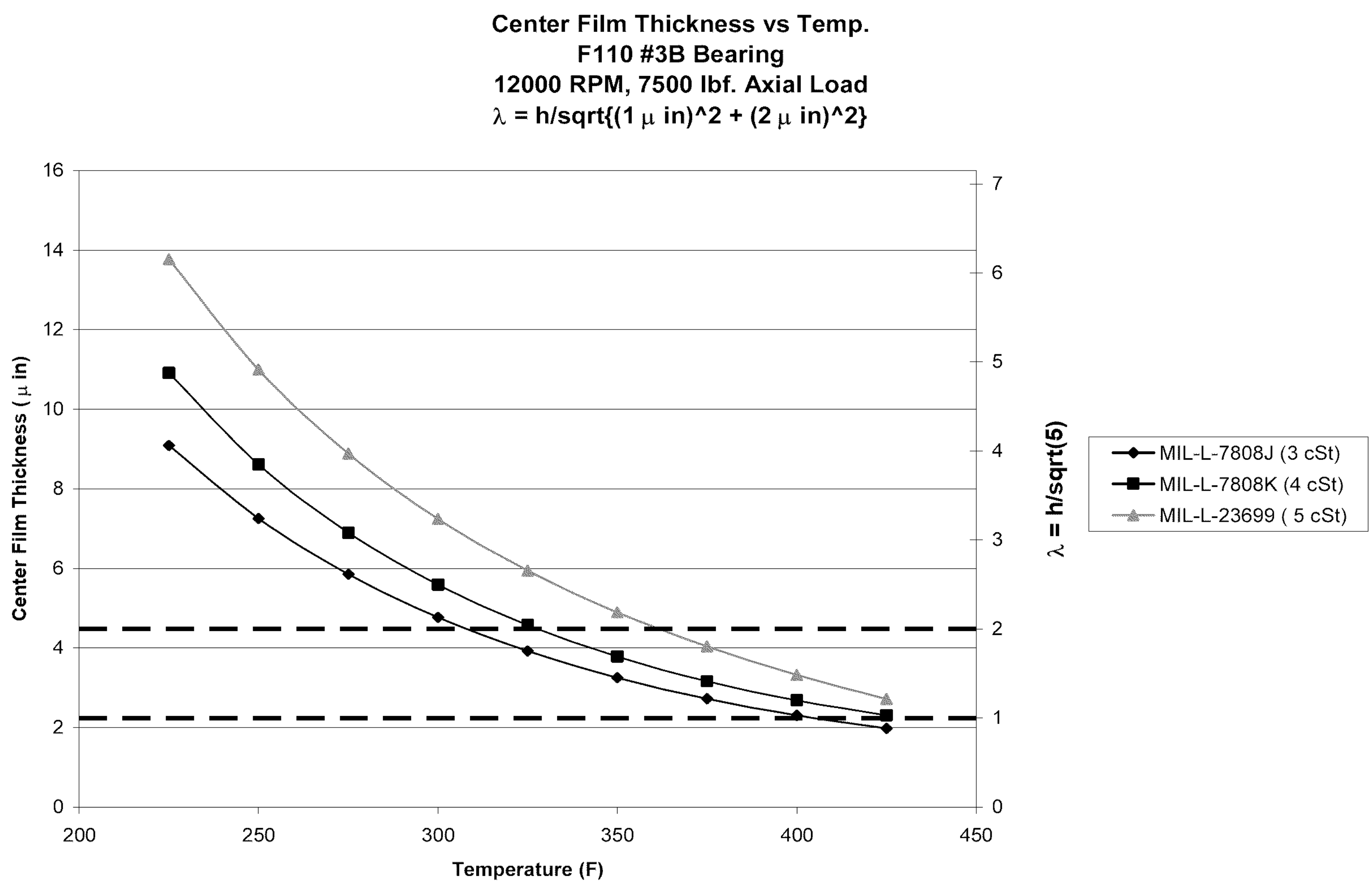
$1 < \lambda < 2$; Reduced Bearing Life

Boundary Lubrication

Significant Metal-to-Metal Contact

$\lambda < 1$; Substantial Reduction in Bearing Life

Film Thickness for Thrust Bearing

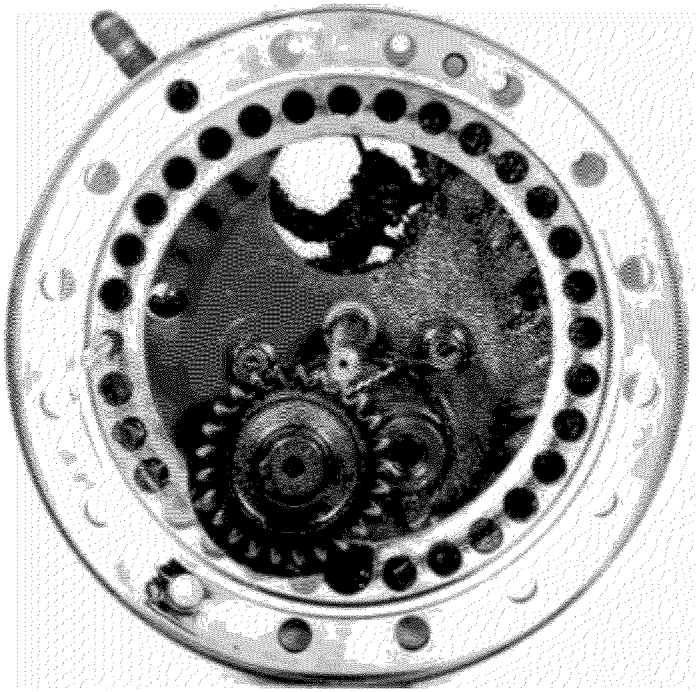


Life multiplying factor @ $\lambda = 2$, is 2.3 x predicted life from LP model

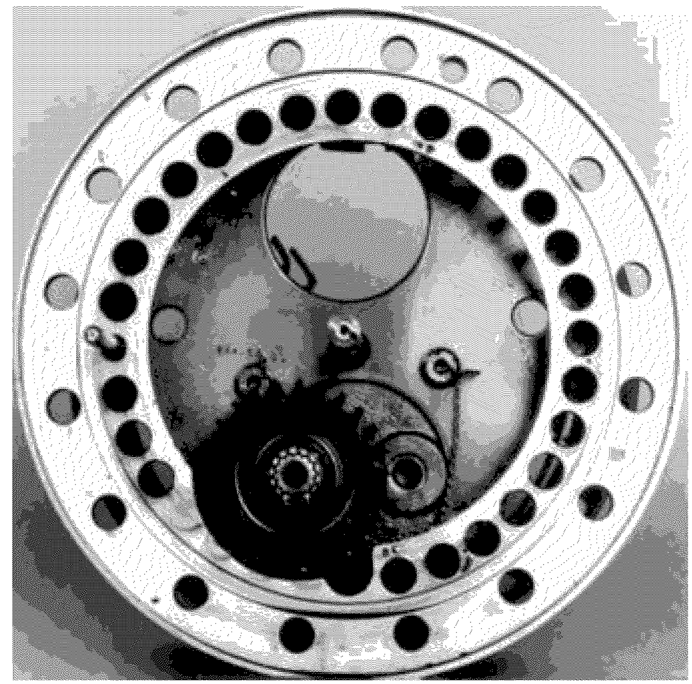
@ $\lambda = 1$, the value is 0.5, 4 x reduction in predicted bearing fatigue life

Reduced Coking - Grade 3 Compared to Grade 4

PRF-L-7808 - Grade 3



PRF-L-7808, GRADE 4



- Enhanced additives and basestock offer much cleaner oils
- Attractive to commercial and military for extended engine time on wing
- In some isolated cases, cleaner oils have shown issues with wear

6

MCCORMICK/PPT/F1:J57TST

Cold-Start Requirements

- The oil viscosity and base stock thermal stability would benefit if we can change the -60 F requirement to -40 F
- JP-8 fuel and hydraulic fluid already have a -40F capability
- AFRL/PRTM has prepared a point paper to address the oil cold-start requirement
- This is being coordinated with
  – US engine companies
  – Air Combat Command Systems Office (ACCSO)
  – ASC/ENF

Cold-Start Requirements

- Results from the study:
  - During the past fifty years Eielson AFB has reached the coldest temperature of - 61 F, Minot has reached - 44 F, Elmendorf has not been below - 40 F
  - Cold weather bases have heaters to protect personnel and equipment when the temperature is below -40F
  - According to engine company survey:
  - Current lube systems not designed for Optimal Ester (OE) cold-start requirements (20,000 cSt, -40 F)
  - To transition OE to existing systems costly qualification testing would have to be done

Performance Attributes

- Next generation steels and lubricants will likely impact tribo-chemistry
- In addition to the tribo-performance (scuffing, wear, surface fatigue) anti-wear additive chemistry should also consider:
  - Oil thermal/oxidative stability
  - Rolling contact fatigue life
  - Corrosion
  - Spall propagation
- Component performance with Grade 4 was not optimal due to a high weighting on thermal/oxidative stability over component performance

Current Oils & Requirements

Cold Weather (Grade 3 or Grade 4?)

•Extreme weather locations

•Auxiliary Power Units

Older Aircraft (STD, CI, or HTS?)

•Is it cost effective/desirable to keep a lower cost type oil?

High Performance Oil (HTS)

•C17, B2 time on wing = thermal stability

•F-22, F-35, F-18, F-16 = high temperature, boundary lubricant additives for newer bearing and gear steels

High Mach (Optimal Ester)

•450 F oil with higher viscosity is attractive

Bearing/Engine Development Programs

- ***Positive communication with the US Navy to do a joint USAF/USN oil program for the future!***

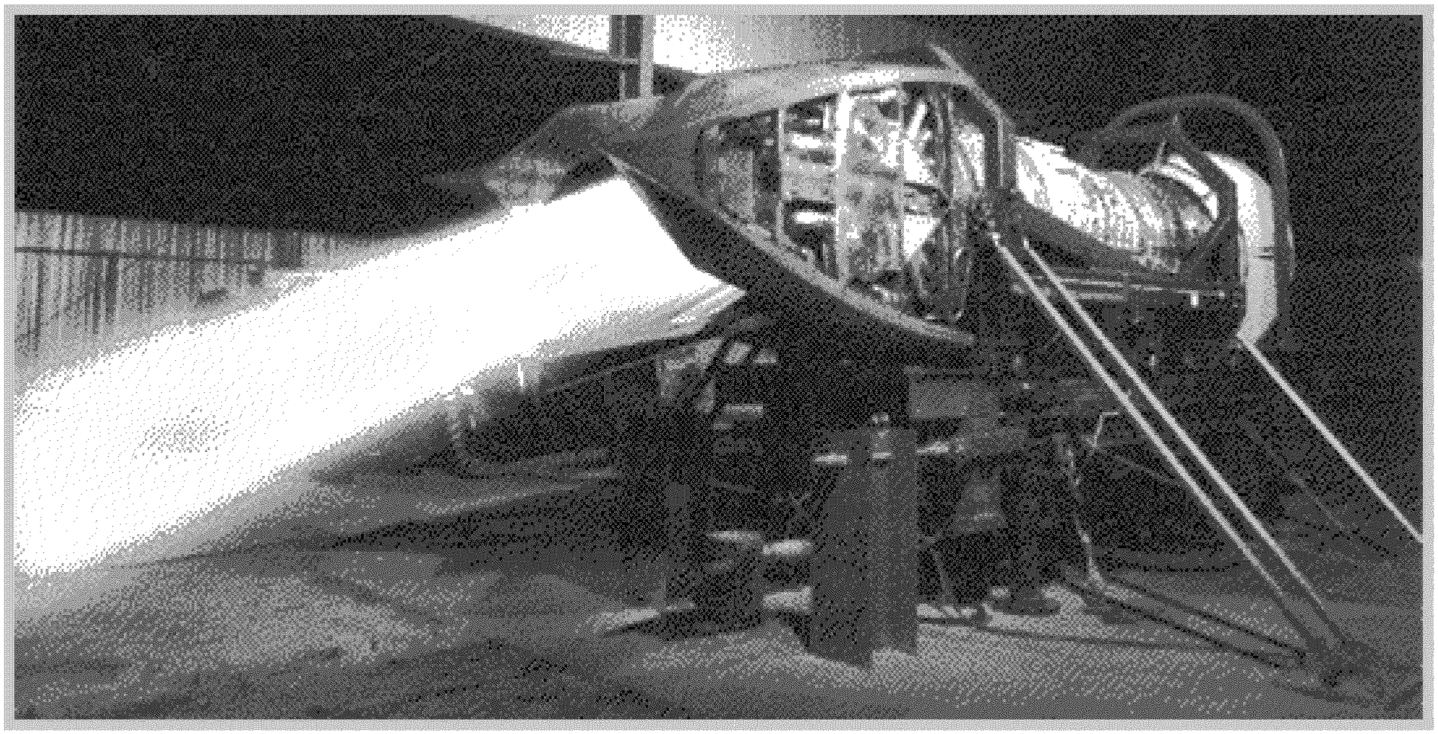
- Considerable bearing and gear development activity over the next five years as part of JSF
- High potential exists to test oils as part of other component development programs
- Tentative plans exist to have AFRL/MLBT SBIR Additive program develop oils/additives and include them in these component programs
- High potential for engine demo of baseline oil in 2005 and improved oil over the baseline in 2007

Summary

- There is a lot of activity right now to do a joint oil program between the USAF and the USN:
  - 5 cSt polyol-ester basestock
  - Enhanced oil in terms of both thermal/oxidative stability and boundary lubricant performance
  - 13,000 cSt at -40 F → no cold start issues for legacy systems at -40F
  - Will offer improved performance for fighter engines and extend oil life for the cargo planes and bombers
- Additionally we will keep a -60 F (Grade 3 or Grade 4) on the QPL for extreme weather applications and APUs

Research and Development of Optimal Ester Turbine Engine Lubricant

16 Jun 2004



Lynne Nelson Lois Gschwender

Optimal Ester Program

- Success will depend on both improved base stocks and additives
- To date, samples from three industrial sources received as
  - Fully formulated gas turbine engine oils
  - Promising base fluids and additives for formulation in-house
- Currently, phase III testing continues on most promising optimal ester candidate, and Phase I testing is ongoing on two recent candidates

Optimal Ester Program - Target Properties and Results

Phase I, Kinematic Viscosity, cSt

°C	Target	Sample		
		A	B	C
100	7.0 min	6.09	5.99	5.99
	5.0-7.0 *			
-40	20,000 max**	23869	19,169	18,724

Optimal Ester Program - Target Properties and Results

Phase I, Antiwear by 4-Ball Wear Scar, 1 hr, 40kg, 600rpm (mm)

	Target	Sample		
		A	B	C
52100, 75°C	0.7 max	0.43	0.53	**0.71**
M-50, 200°C	1.0 max	0.49	-	-

Optimal Ester Program - Target Properties and Results

Phase I, Corrosion-Oxidation, 48 hr, 165 ml, **220°C**

metals: Al, Ag, Bz, steel, M-50, Mg (WE-43), Ti, Inconel 718

	Target	Sample A	Sample B	Sample C
Visc. chg. %	-5 to 25	12.30	14.6	23.6
Acid # chg. mg KOH/gm	4.0 max	1.20	0.81	2.09
Fluid loss, %	8.0 max	3.25	3.1	3.9
Metal wt. chg.	0.2 max	pass	pass	pass
Mg, mg/cm^2	0.4 max	-0.01	-0.08	0.00

Optimal Ester Program - Target Properties and Results

Phase I, Corrosion-Oxidation, 48 hr, 165 ml, **232°C**

metals: Al, Ag, Bz, steel, M-50, Ti, Inconel 718 (no Mg, WE-43)

	Target	Sample A	Sample B	Sample C
Visc. chg. %	-5 to 25	24.10	**30.2**	**36.4**
Acid # chg. mg KOH/gm	4.0 max	3.76	**7.0**	**6.71**
Fluid loss, %	8.0 max	4.40	4.30	4.60
Metal wt. chg. mg/cm^2	0.2 max	pass	pass	pass

Optimal Ester Program – Target Properties and Results

- Static Coke Formation – mg coke/gram oil
  Test conditions: 300°C, 3 hour test time, shim stock specimens, 4 test average

Target	Sample		
	A	B	C
49.4	33.5	re-run	re-run

Optimal Ester Program - Target Properties

Phase II, Elastomer Compatibility, 70 C, 70 hours

Sample A	% Swell	Tensile str, **% Change**	Elongation, **% change**
(Target)	25, max	+/-50	+/-50
AMS 7276, Fluorocarbon	4.9	**126.6**	-45.0
AMS-R-83485, Viton GLT	5.5	**56.9**	-5.6
AMS 3383, Fluorosilicone	5.4	**60.0**	10.0

Optimal Ester Program - Target Properties

Phase II, Elastomer Compatibility, 205 C, 70 hours

Sample A	% Swell	Tensile str, **% Change**	Elongation, **% change**
(Target)	25, max	+/-50	+/-50
AMS 7276, Fluorocarbon	17.3	-13.1	**-73.0**
AMS-R-83485, Viton GLT	12.2	15.7	-38.7
AMS 3383, Fluorosilicone	3.8	16.7	-8.0

Optimal Ester Program – Phase II Ryder Gear Data

- Navy ran **Sample A** in April 03
- Two gear sets run
  1) A side = 2866 ppi, B side = 2884 ppi
  2) A side = 2677 ppi, B side = 3068 ppi
- Average of 4 gears = 2874; Herco reference rating = 2776, making Relative Rating of 104% (comparable to some HTS oils)

Optimal Ester Program - Target Properties

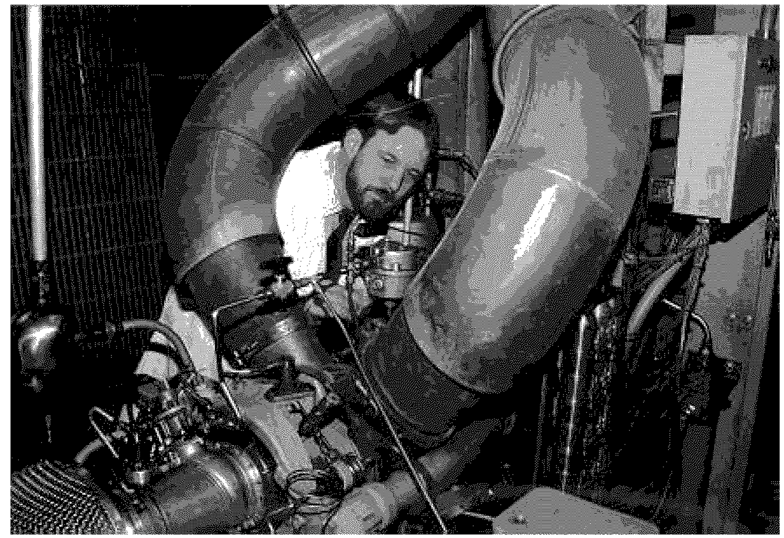
Phase II, Dynamic Coking - Bearing Deposition, 199°C oil sump, 260°C bearing, 200 hours (with a check at 100 hour point)

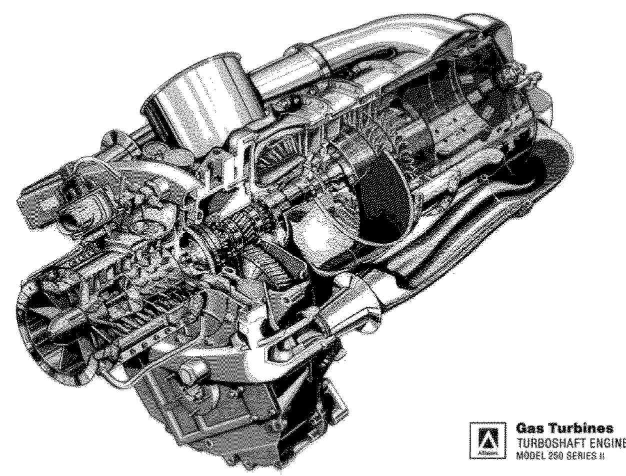
(these are Navy's test temps, per MIL-PRF-23699, HTS)

	Target	Sample A
	100 hr/200 hr	100 hr/200hr
Deposit Rating	20 / 40 max	25 / 39
Oil consumption, ml	2000 / 4000max	- / 4,040
Viscosity change @40°C,	0 to 15 / 0 to 20	5.7 / 10.4
Acid # Change, mg KOH/gm	1.0 max	0.38 / 0.48

T63-A-700 Turboshaft Engine Evaluation

- Final Phase III optimal ester test
- Determine type/quantity of deposits and mechanical condition of engine at overhaul
- 250 hour engine endurance test, with oil in temp @ 300 F, #7 bearing temp @ 380 F





T 63 Engine Test
Candidate A results

- Engine seized after ~49 hours due to a coke- plugged fuel nozzle **(optimal ester did <u>not</u> cause the engine to seize)**
- Optimal ester looked fine; % Viscosity change @ 100 C was 1.0%; change in TAN was 0.60
- T 63 output shaft was repaired; a Grade 4 oil was completed in Feb 04 - baseline optimal ester conditions (175 hrs, check #8 bearing, then continue to 250 hrs)
- Candidate A optimal ester will be run in the T63 for 250 hr optimal ester test condition - currently scheduled for fall 2004.

Pratt & Whitney PW6000 engine test

- 50 hour commercial engine test was run on Candidate A optimal ester @ MTU in Munich, Germany in Aug/Sep 04
- Engine test was conducted thru a joint CRADA with AFRL and Pratt & Whitney
- Still awaiting details of this test from P&W

Summary & Conclusions

- Candidate A continues to look promising in all rig testing
- AFRL is repeating elastomer compatibility test
- Candidate A will be run in T63 engine test using optimal ester test conditions (250 hrs) in the fall 2004.

Summary

- Candidates B & C are in initial phase of evaluation – AFRL is currently working with vendor to improve formulations
- Tribological performance was evaluated further with Sample A
- Limited testing in fall 2003 did not show any appreciable improvement

Summary and Conclusions

- AF is now looking to use these optimal ester fluids in specialized applications, such as high Mach engines
- AFRL continues to encourage further cooperation among all parties involved with this effort
- AFRL is hopeful Phase II SBIR results will have positive impact on optimal ester technology

MIL-PRF-23699 Gas Turbine Engine Oil

Military Aviation Fluids & Lubes Workshop
15 – 17 June 2004

John Shimski (john.shimski@navy.mil)
Naval Air Systems Command
AIR-4.4.5, Fuels and Lubricants Division
Patuxent Rive, Md
(Com: 301.757.3412, DSN: 757.3412)

AIR-4.4.5 Lubricants Group

- Primary Agency for development and qualification of naval aviation propulsion system lubricants since 1962
  - MIL-PRF-23699 Gas Turbine Engine Oil
  - DOD-L-85734 Helicopter Transmission Oil
  - SAE J-1966 and J-1899 piston engine oils
  - MIL-C-85704 Compressor Gas Path Cleaners
- Complete in-house test capability at Patuxent River, MD
  - Physical, chemical and analytical analysis
  - Bench test simulators
  - T63 turboshaft engine
- Product development, qualification and in-service support

AIR-4.4.5 Lubricants Group Continued

- Strong industrial ties
  - MIL-PRF-23699 approval is an unofficial prerequisite for commercial oil approval (used in > 95% of the free world's airlines)
  - Product demand gives the Navy leverage for new product development
    - unique military needs
    - emerging engine technology requirements
- Global product availability
  - Military distribution system (green cans)
  - FMS / NATO availability (NATO O-156)
  - Commercial items (brand name products)

Product Chronology

- MIL-L-23699 Evolution

  Continuous Improvement

  with Minimal Risk

MIL-L-23699
Established
STD = 3

1962

MIL-L-23699 C
STD = 29

1986

MIL-L-23699D
STD

1990

MIL-L-23699 E
Corrosion Inhibition
(C/I) Added

1994

MIL-PRF-23699 F
High Thermal Stability
(HTS) Added

1997

MIL-PRF-23699 H
C/I +HTS
Next Goal

2007

Transmission
Spec Established
DoD-L-85734

1986

Fleet Introduction
Optimum
Transmission Oil

2007?

NAVAIR

4

MIL-PRF-23699 History

- Rev "D", 9 Oct 1990 - One class of performance only
  - No special features
  - Three NSN's for three size containers
- Rev "E", 25 August 1994 - two performance classes
  - Standard (STD) - traditional Rev "D" type oil
    - NSN's transferred to Corrosion Inhibited products
    - remained on Qualified Products List (QPL) for emergency use
  - Corrosion Inhibited (C/I) oil
    - adopted NSN's previously used by STD oil
      - transparent conversion process
        - » least intrusive method to change over
      - seamless logistics conversion
        - » consumes present stock in the supply pipeline
    - identical in performance to STD but with add C/I feature

MIL-PRF-23699 History Continued

- Rev “F”, 21 May 1997 - three performance classes & PRF
  - High Thermal Stability (HTS) class added
    - high cleanliness, high performance additives (high cost)
    - intended for “hot” engines where oil deposits are problems
    - three new NSN’s added for various size containers
  - C/I class
    - remains as primary oil for military use
  - STD class
    - retained for emergency use
  - “PRF” = “Performance” specification
    - indicates compliance with 1995 Sec. of Defense mandate that all specifications be performance based documents

MIL-PRF-23699 History Continued

- Today
  - All oil performance classifications are completely compatible with each other
    - no harm will occur to either the equipment or the oil if mixed
    - mixing C/I, HTS and STD oils together will diminish the enhanced property proportionally and the performance level will revert to that of a STD product
  - C/I is the preferred class to be used for all applications
    - NAVAIRINST 10350.4A, 19 Mar 1999 - "Utilization of Aircraft Engine and Helicopter Transmission Lubricating Oils"
      - available at (www.nalda.navy.mil/instructions/default.cfm)
  - New NSN's issued for STD class oil (three sizes)
    - by US Army request, June 2001

Corrosion Inhibited Oil

Background

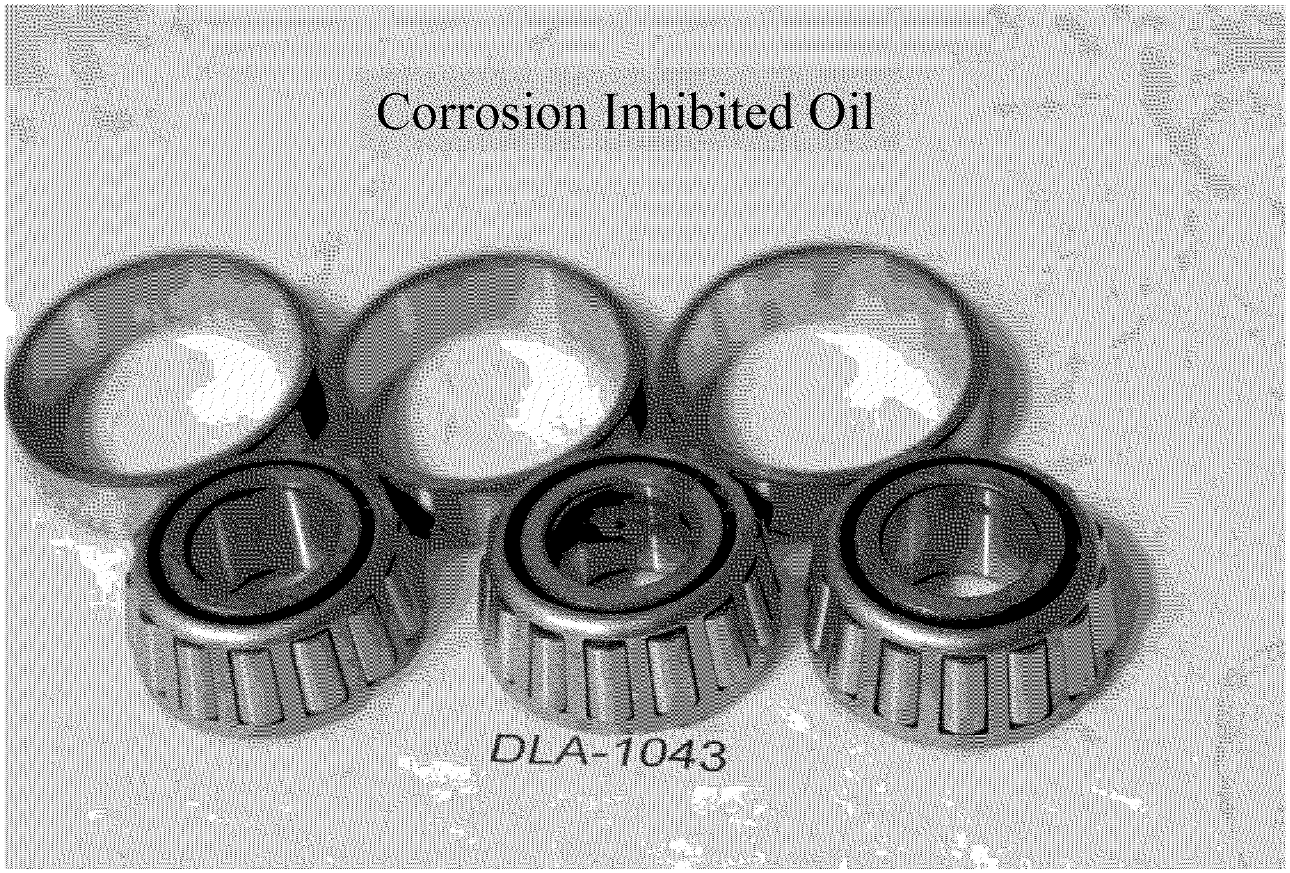
- WHY?: 50% of bearings rejected at OH are due to static corrosion (>$5M in a 1985 study for parts alone)
  - corrosion forms during periods of non-operation
  - addition of on site preservative treatments not practical
  - decision to put C/I into operational oil made in 1990
- Rev “E” published in August 1994
  - NSN’s applied in April 1995
  - First C/I contracts awarded in early 1996
  - First deliveries in Summer 1996
  - Existing long term contracts for Rev “D” STD class oils continued to be filled into 1997

Performance Comparison

Corrosion Inhibition- Lab Test

Performance Comparison

Corrosion Inhibition- Lab Test



Performance Comparison
Corrosion Inhibition – Engine Hardware

High Thermal Stability Oil

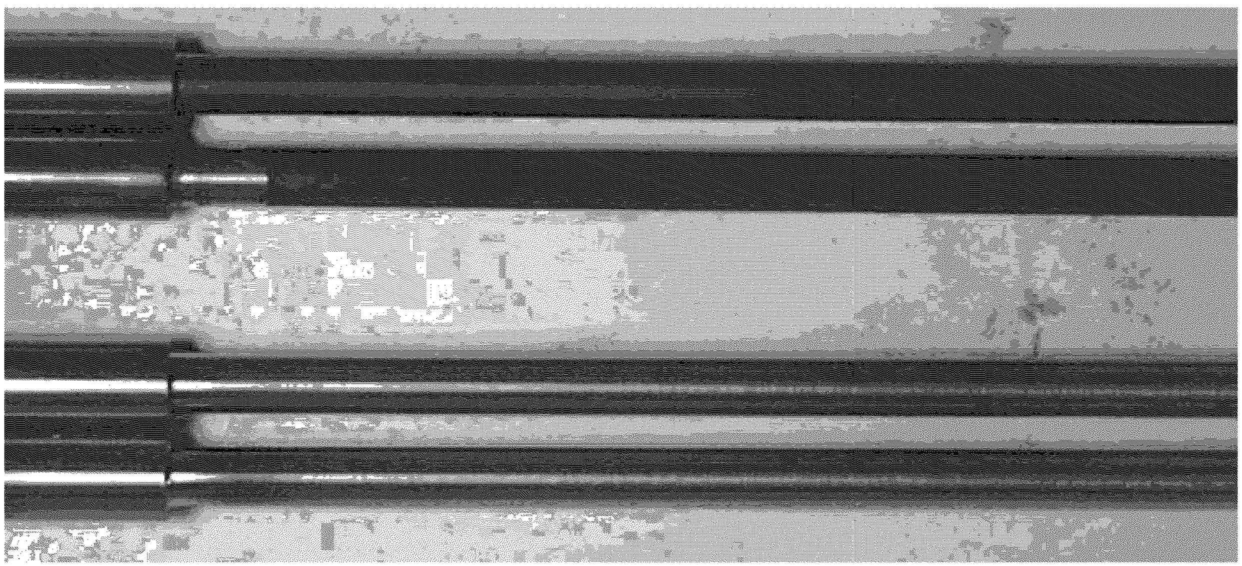
Background

- Specification change driven by field reports:
  - Heavy Oil Deposits in:
    - TF-34 engines (Navy S-3 aircraft)
      - Shedding oil deposits load & by-pass filters then plug jets
    - US Army AGT 1500 Abrahams Tank engine
  - Caused by hot running engines / quick shutdowns
    - Carrier deck operations amplify heat soaks
    - Tank engine exhaust regenerator retains residual heat
  - Problems caused:
    - In-flight shutdowns / mission aborts
      - Low TBR’s
    - Increased maintenance and part cleaning

Performance Comparison

Cleanliness – Test Rig

High Temperature Deposition Test



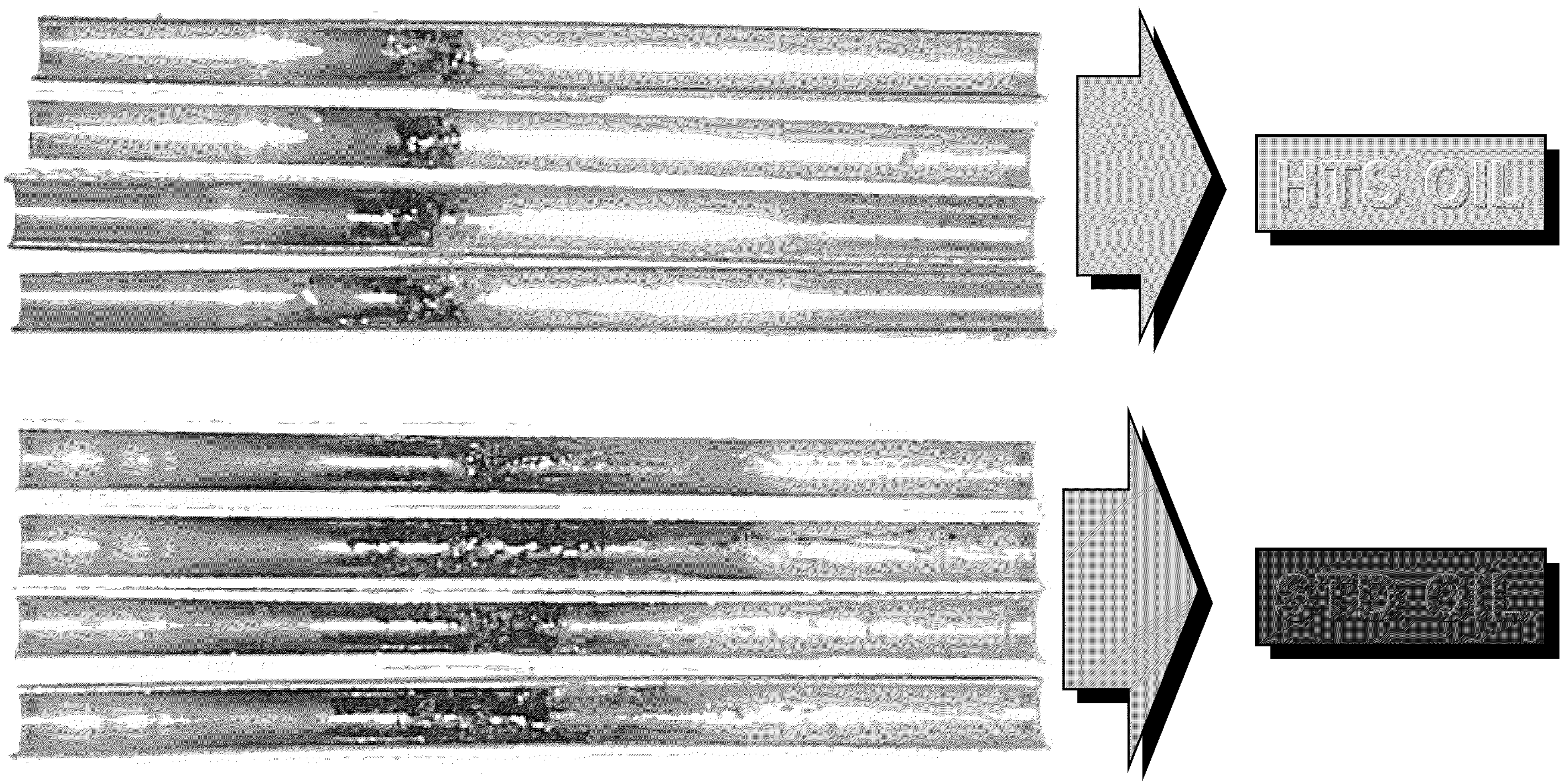
STD OIL

HTS OIL

Performance Comparison

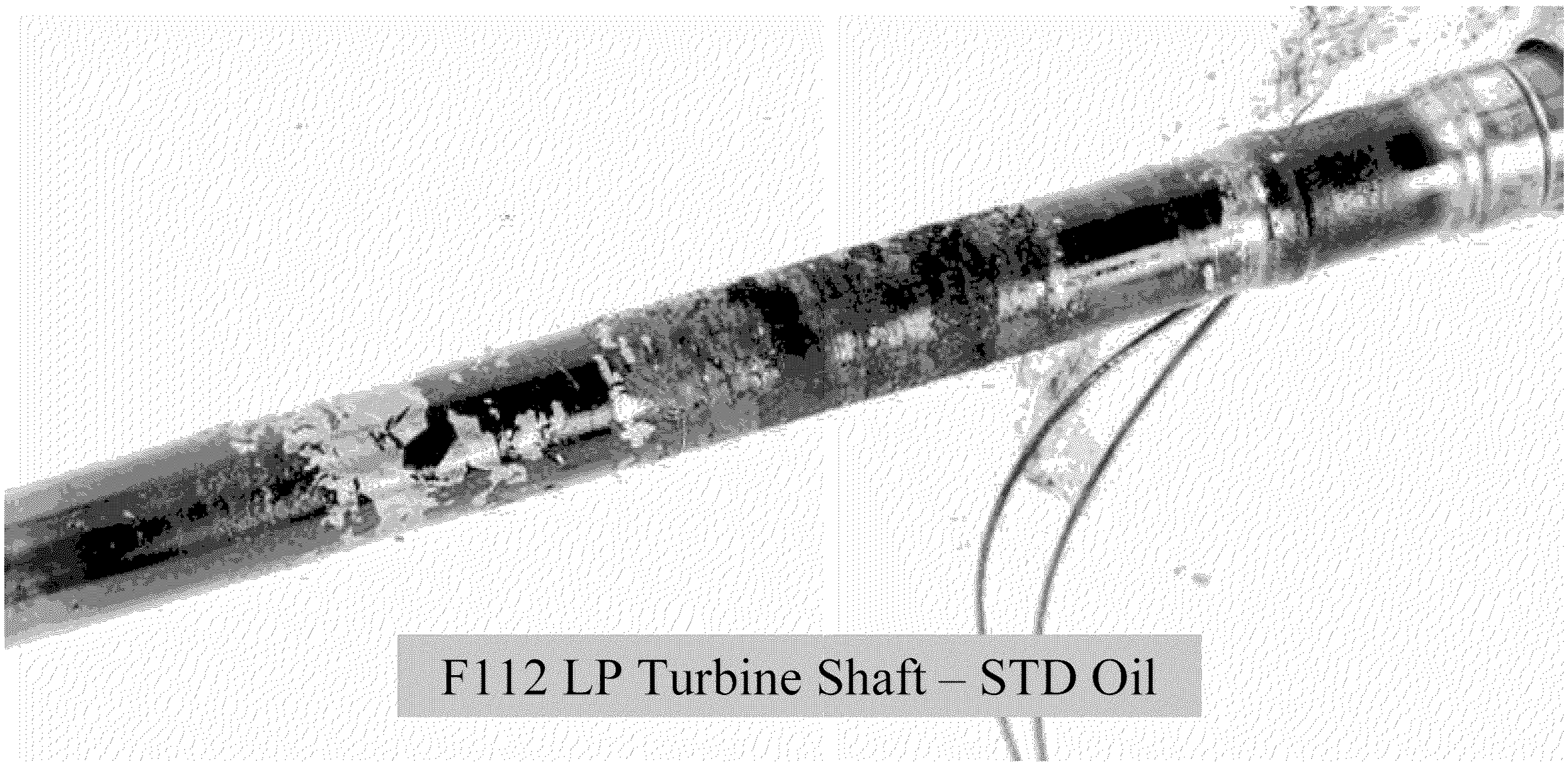
Cleanliness – Test Rig

Vapor Phase Coker Test



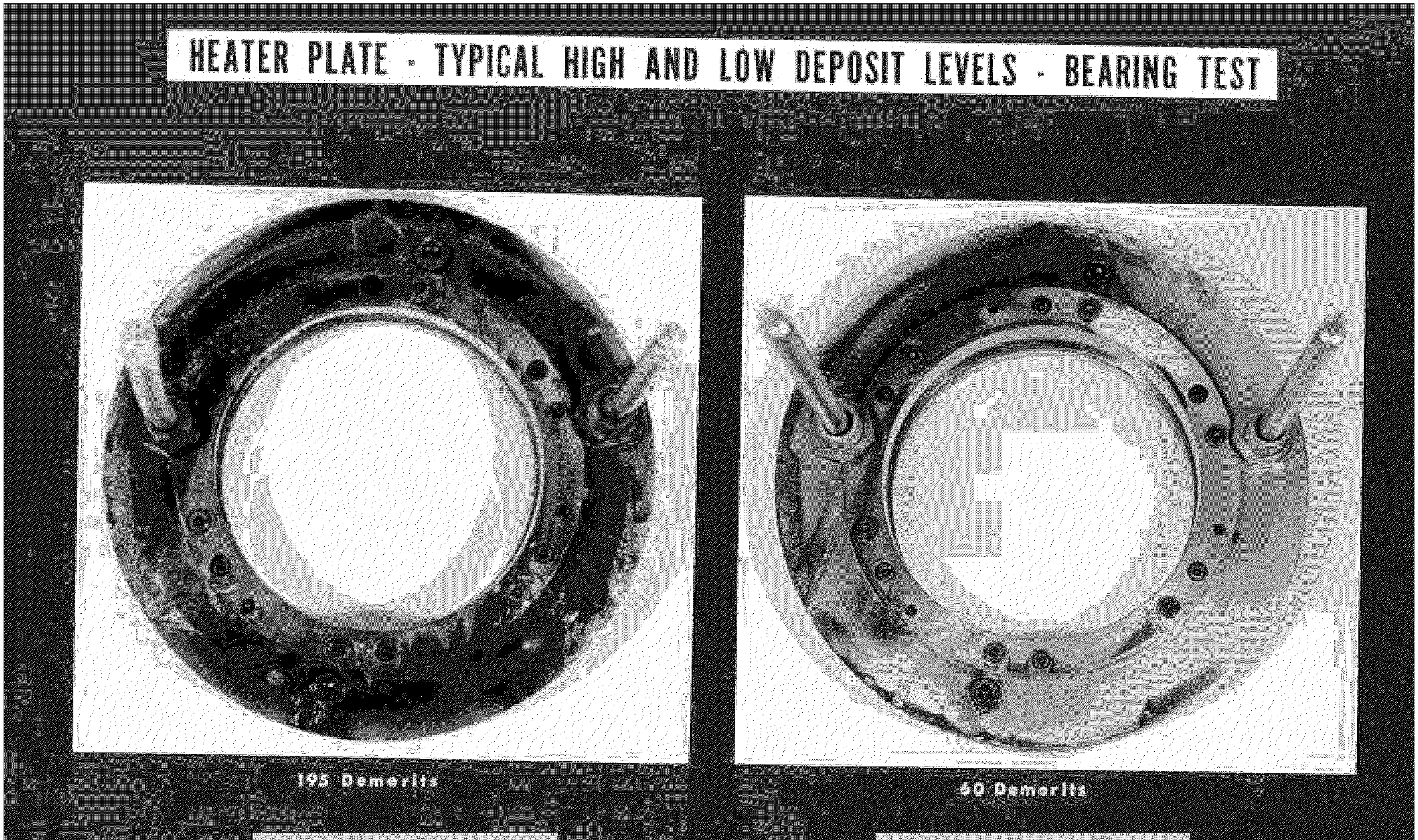
Performance Comparison

Cleanliness – Test Engine Hardware



Performance Comparison

Cleanliness – Test Rig

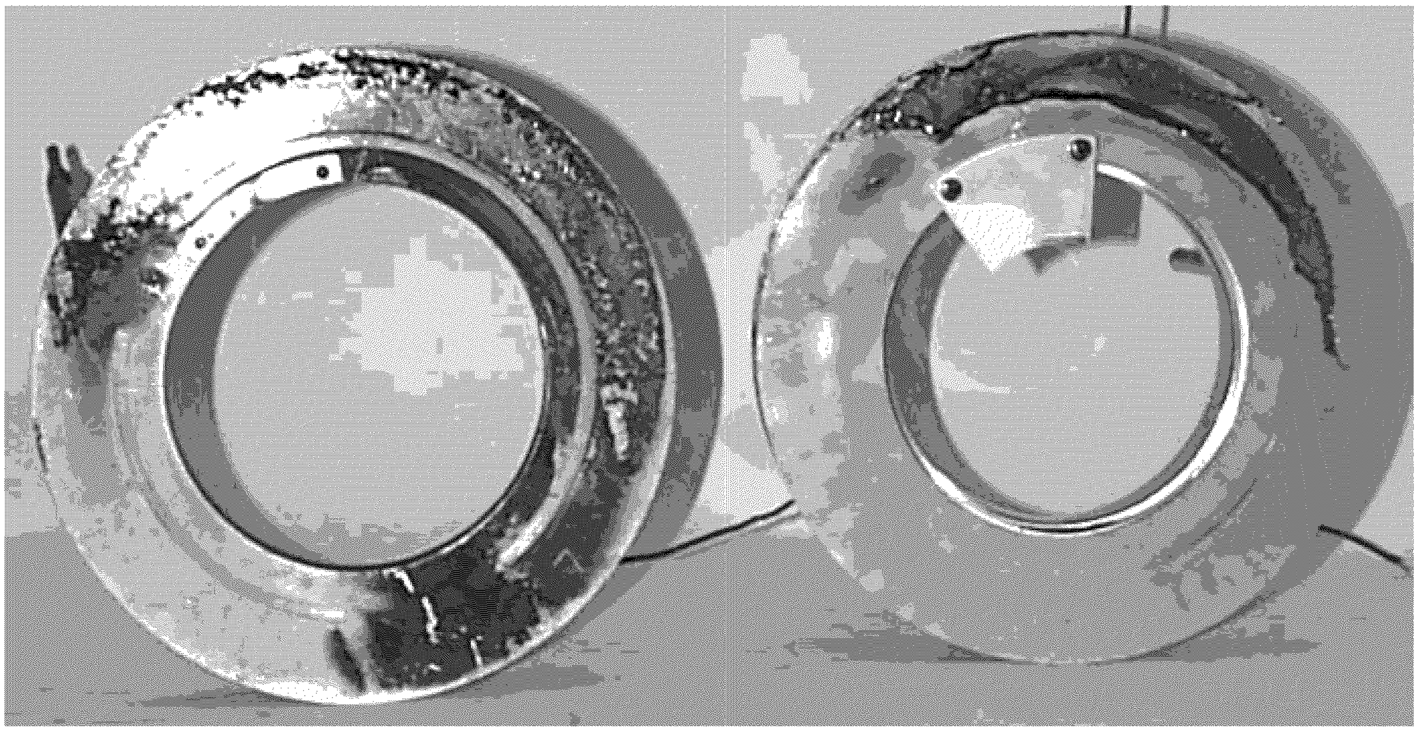


Failing Results

Typical STD Oil

Performance Comparison
Cleanliness-Test Rig

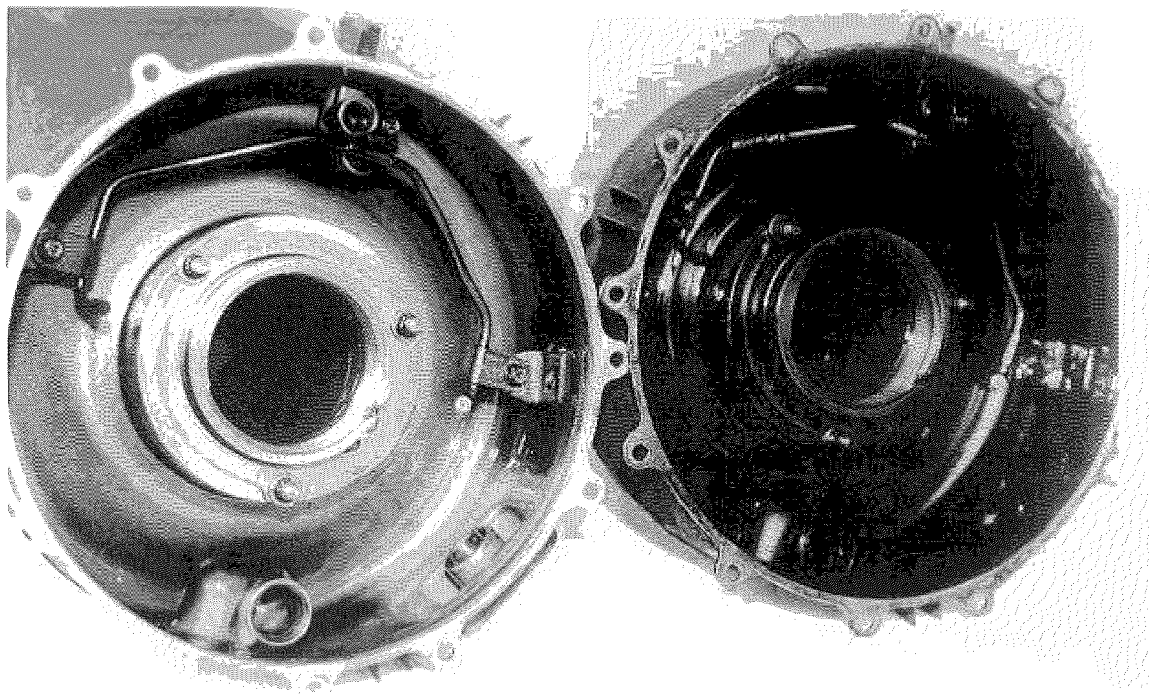
100 Hour High Temperature Bearing Rig Test



STD OIL

HTS OIL

Performance Comparison
Cleanliness in Field Hardware



HTS Class

STD Class

Figure 3
C-SUMP COVERS AFTER 758 ENGINE THERMAL CYCLES

MIL-PRF-23699

Future Plans – Near Term

- MIL-PRF-23699G planned for October 2004
  - Technical Changes
    - Define better resolution for HTS Class oils
      - 200 hour High Temperature Bearing Rig Test
      - 250 hour T63 Engine Test
    - New Test to measure Corrosion Resistance
      - ASTM D-1743, Modified for aviation oil
    - Boron and Sodium trace metal elements added to NOAP
      - Indicators of oil cross-servicing
  - Editorial and format changes
  - Revise Qualified Products List

MIL-PRF-23699

Future Plans- Mid Term

- MIL-PRF-23699 "H" (~ Sept 2007 ?)
  - Combine performance requirements into a single HTS + C/I product
    - High cleanliness and oxidative stability
    - Good corrosion protection
    - Good antiwear (AW) properties and load carrying capacity
  - Single oil product to stock for all Naval applications
    - Simplified logistics
  - Trade-offs
    - Not all models need HTS performance (today)

MIL-PRF-23699

Future Plans- Mid Term (continued)

- Numerous technical challenges ahead
  - Requirements focused on Military needs
  - Provide C/I protection while maintaining AW features and HTS cleanliness levels
    - Competition of surface active additives for metals
    - Thermally and oxidatively stable C/I and AW additives
  - Evolution of engine materials
    - Hybrid bearings
    - New alloys for gears and bearings
    - High temperature elastomers
  - Backward compatibility
    - Must be a “drop-in” for existing systems

MIL-PRF-23699

Future Plans- Long Term

- Currently both the US Navy and USAF maintain separate lubricant specifications for gas turbine engine oils
  - MIL-PRF-23699 with Class STD, C/I and HTS
  - MIL-PRF-7808 with Grade 3 and Grade 4
- US military gas turbine engine designs are becoming multi-service components (JSF and beyond)
- Lube system requirements are becoming non-service specific leaving room for a common military lubricant
- US Navy – USAF have begun discussions to define the performance requirements for such a common product

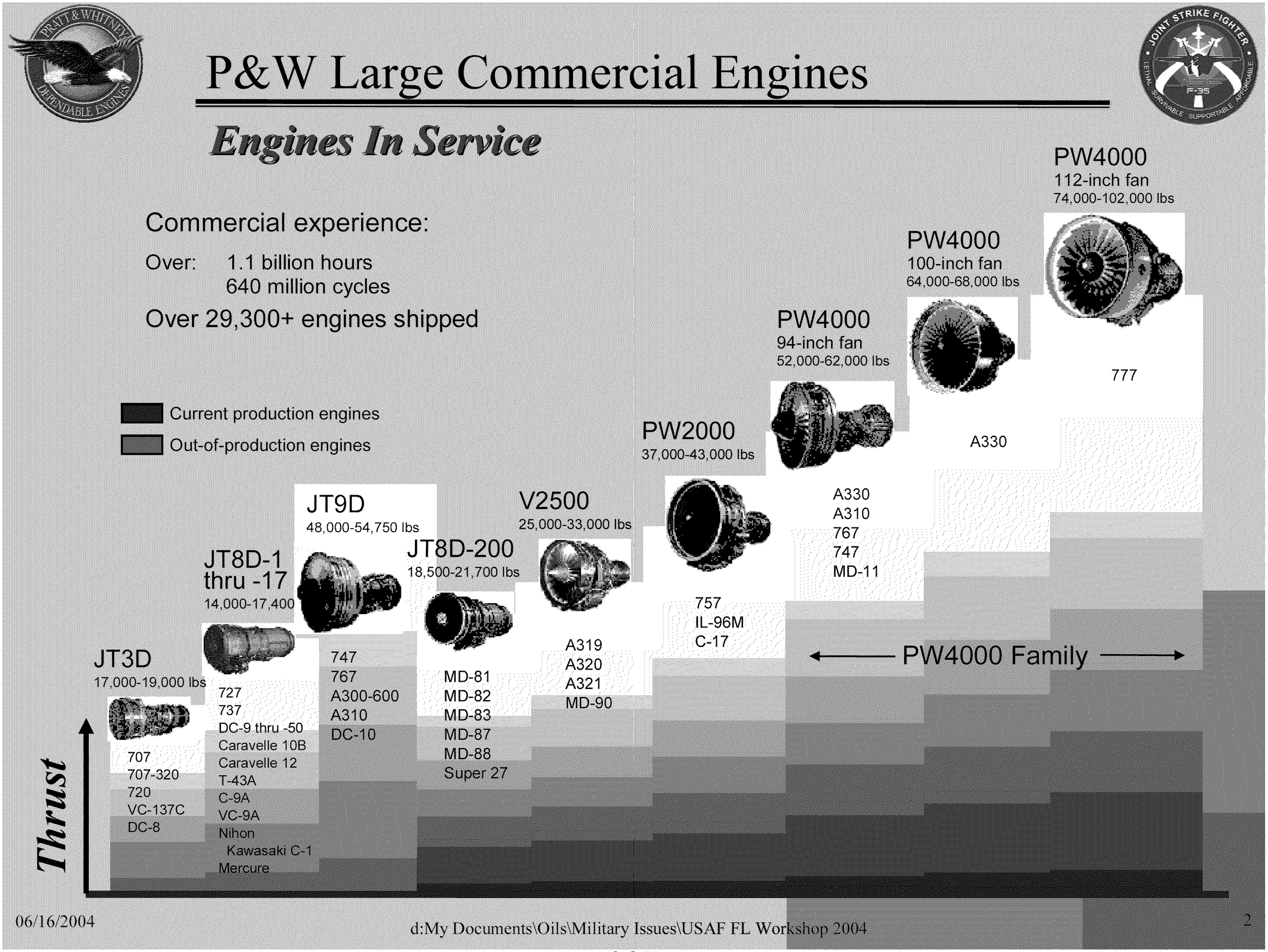
MIL-PRF-23699 - Summary

- MIL-PRF-23699 performance requirements have steadily evolved over the last 40 years to meet the engine and service demands of Naval Aviation
- New engine designs lean toward HTS oil performance
- Corrosion inhibition for Naval aviation engine applications is a necessary requirement to maintain mission readiness
- The need for an HTS- C/I oil is here today
- In the near future, a common lubricant for military aviation gas turbine engines is possible

Future Propulsion System Lubrication Considerations

- Mechanical System Design Issues
- Bearing Materials Development
- Future Lubricant Requirements
- Summary: Need For Synergism !

Curt Genay, Ron Yungk , Bill Ogden & Herb Chin


P&W Large Commercial Engines
Engines In Service
Commercial experience:
Over: 1.1 billion hours
640 million cycles
Over 29,300+ engines shipped
Current production engines
Out-of-production engines
JT3D
17,000-19,000 lbs
707
707-320
720
VC-137C
DC-8
JT8D-1
thru -17
14,000-17,400
727
737
DC-9 thru -50
Caravelle 10B
Caravelle 12
T-43A
C-9A
VC-9A
Nihon
Kawasaki C-1
Mercure
JT9D
48,000-54,750 lbs
747
767
A300-600
A310
DC-10
JT8D-200
18,500-21,700 lbs
MD-81
MD-82
MD-83
MD-87
MD-88
Super 27
V2500
25,000-33,000 lbs
A319
A320
A321
MD-90
PW2000
37,000-43,000 lbs
757
IL-96M
C-17
PW4000
94-inch fan
52,000-62,000 lbs
A330
A310
767
747
MD-11
PW4000
100-inch fan
64,000-68,000 lbs
A330
PW4000
112-inch fan
74,000-102,000 lbs
777
PW4000 Family
Thrust
06/16/2004
d:My Documents\Oils\Military Issues\USAF FL Workshop 2004
2

P&W Large Military Engines

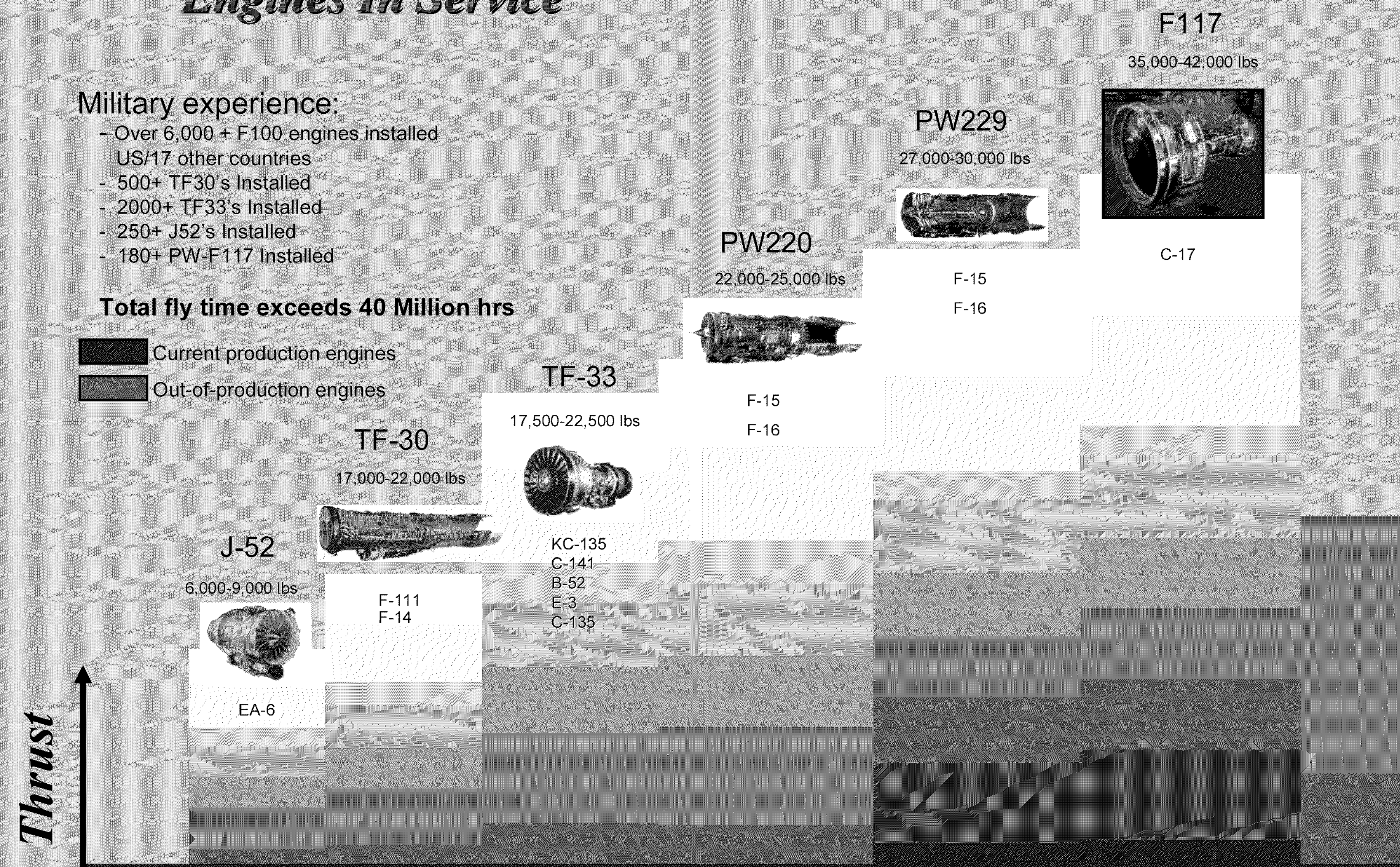
Engines In Service

Military experience:
- Over 6,000 + F100 engines installed US/17 other countries
- 500+ TF30's Installed
- 2000+ TF33's Installed
- 250+ J52's Installed
- 180+ PW-F117 Installed

Total fly time exceeds 40 Million hrs

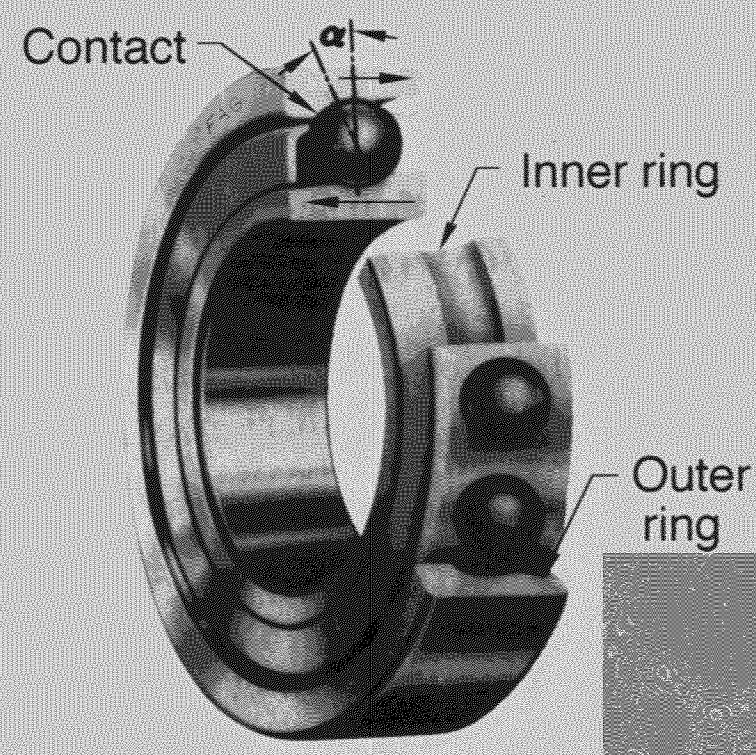
Current production engines

Out-of-production engines



The Bearing / Lubricant System

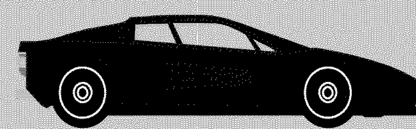
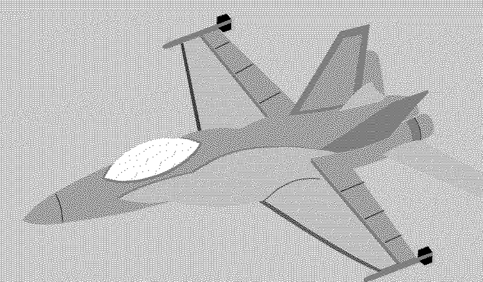
A Bearing Is Not a Component. It Is a System !



Advanced Aircraft Engine Mechanical Systems Enable Improved Performance and Economic Designs !

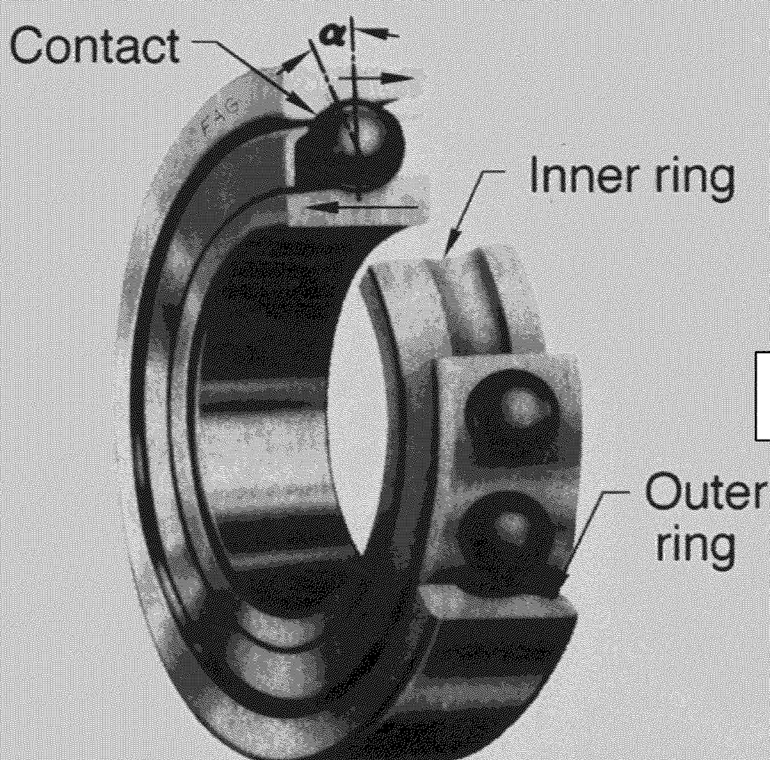
The Bearing / Lubricant System

To Put Things Into Perspective: Car vs. Jet Engine

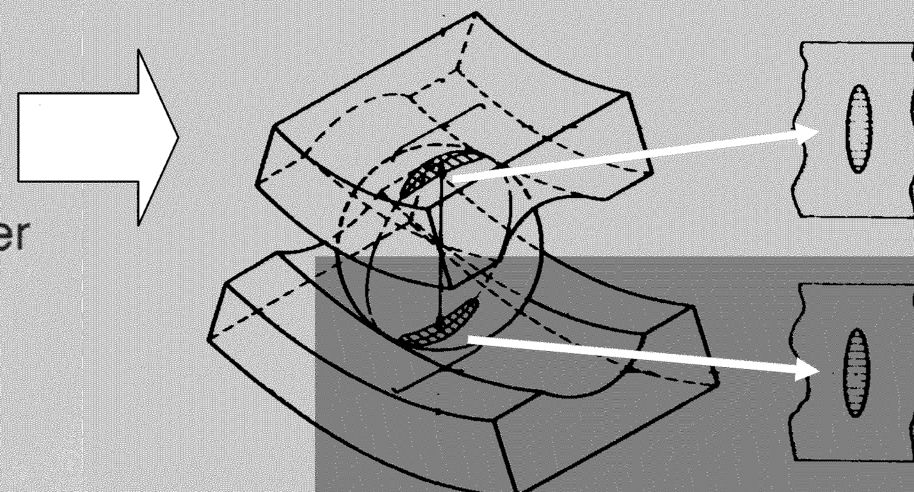
Service Requirements		
dN = Bore X Speed	< 0.6	1.5 to 2
Operating Temp	up to 200°F	250 to 315°F
Hertzian Stress	< 200 ksi.	up to 275 ksi
λ Ratio	2 to 4	~ 1
Bearing Grade	ABEC 1	ABEC 5 or 7

The Bearing / Lubricant System

Bearing Contact Ellipse Is Where All the Action Occurs

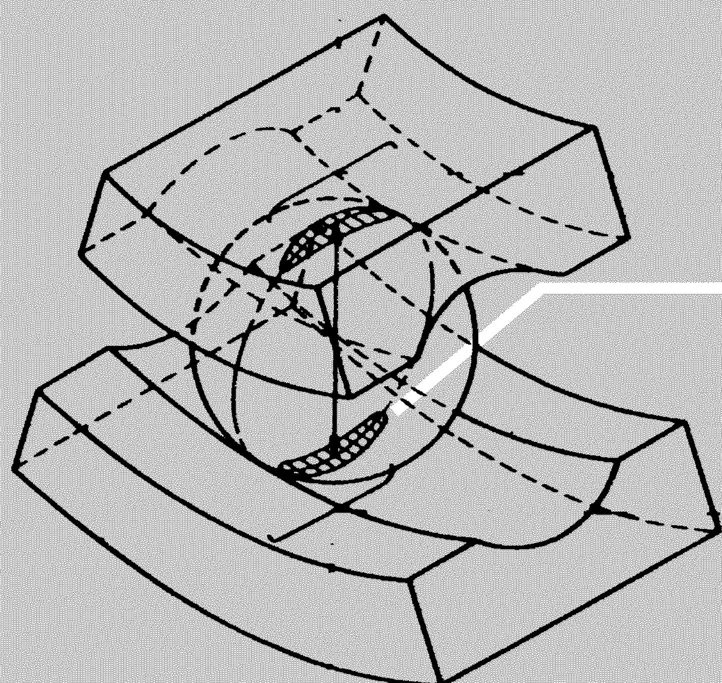


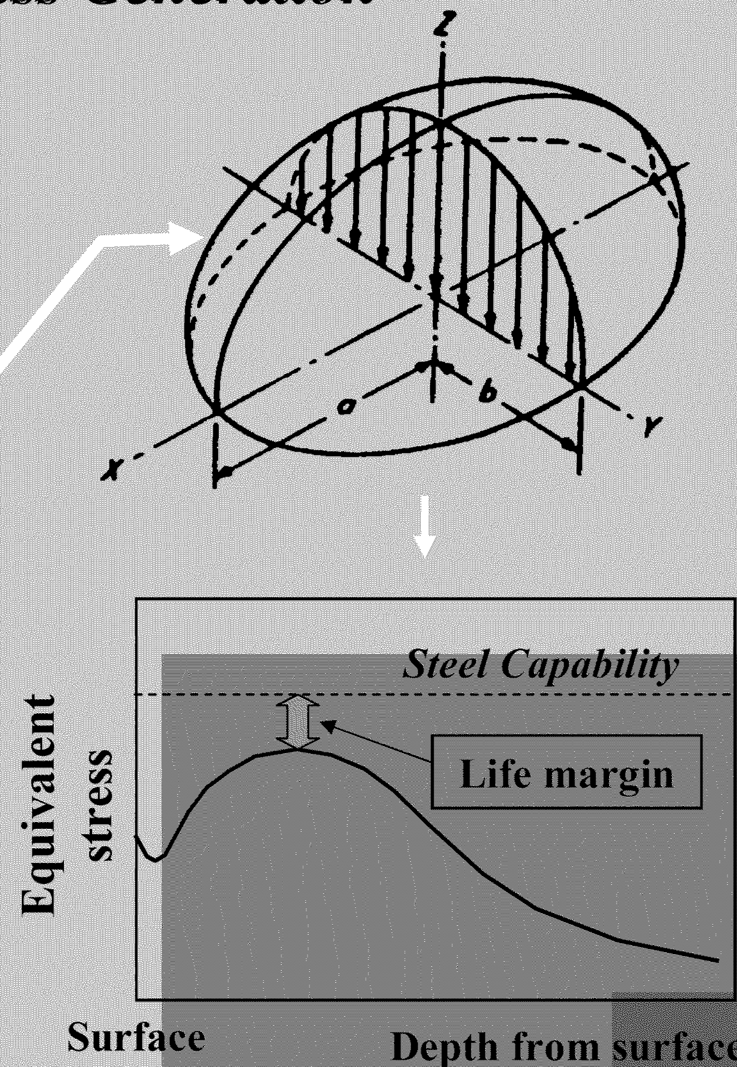
Load at the Ball / Race Contact
Is an Elliptical Pressure Area



The Bearing / Lubricant System

The Hertzian Contact - Stress Generation





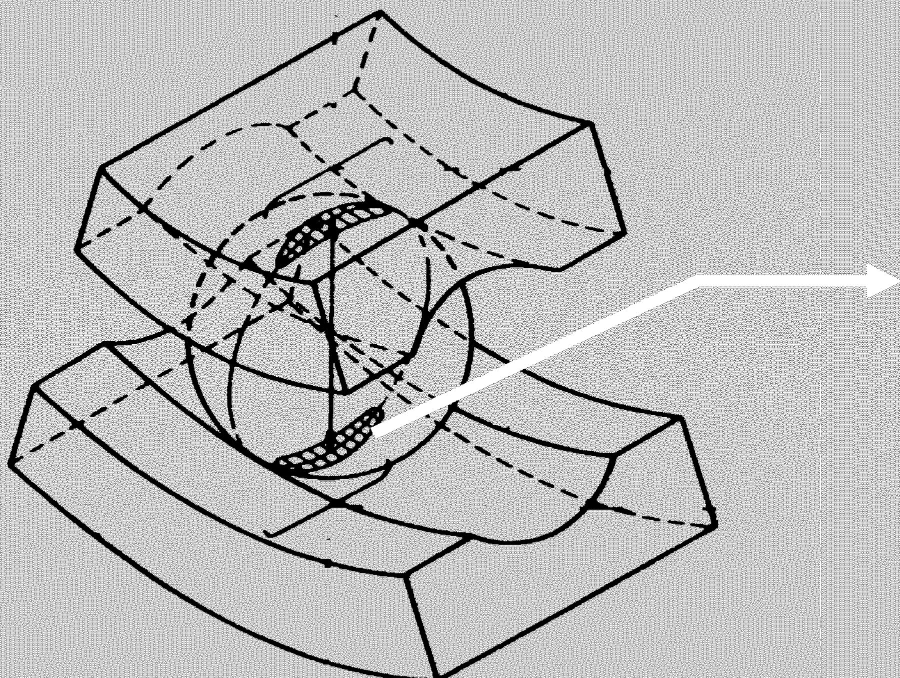
Hertzian Stress

Mean Stress = P/A

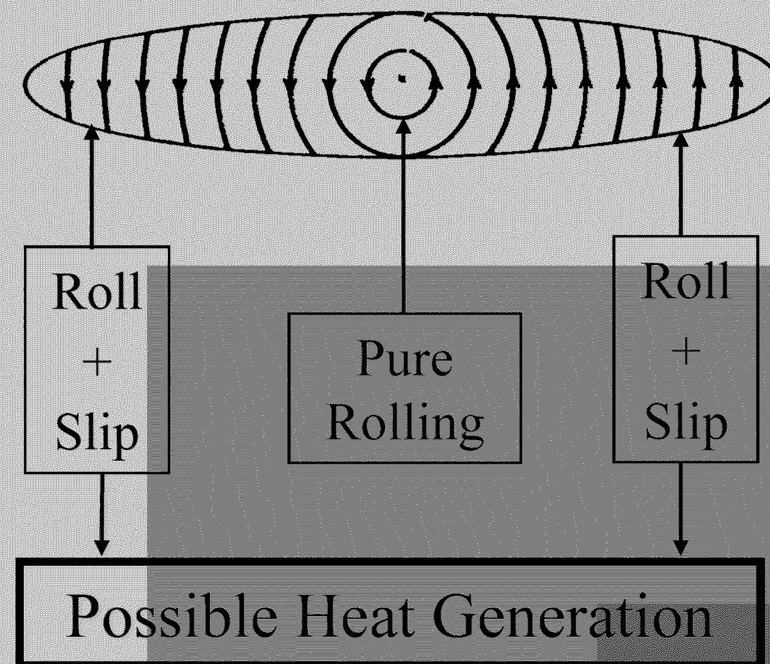
Max. Stress = 1.5X Mean Stress

The Bearing / Lubricant System

The Hertzian Contact - Heat Generation

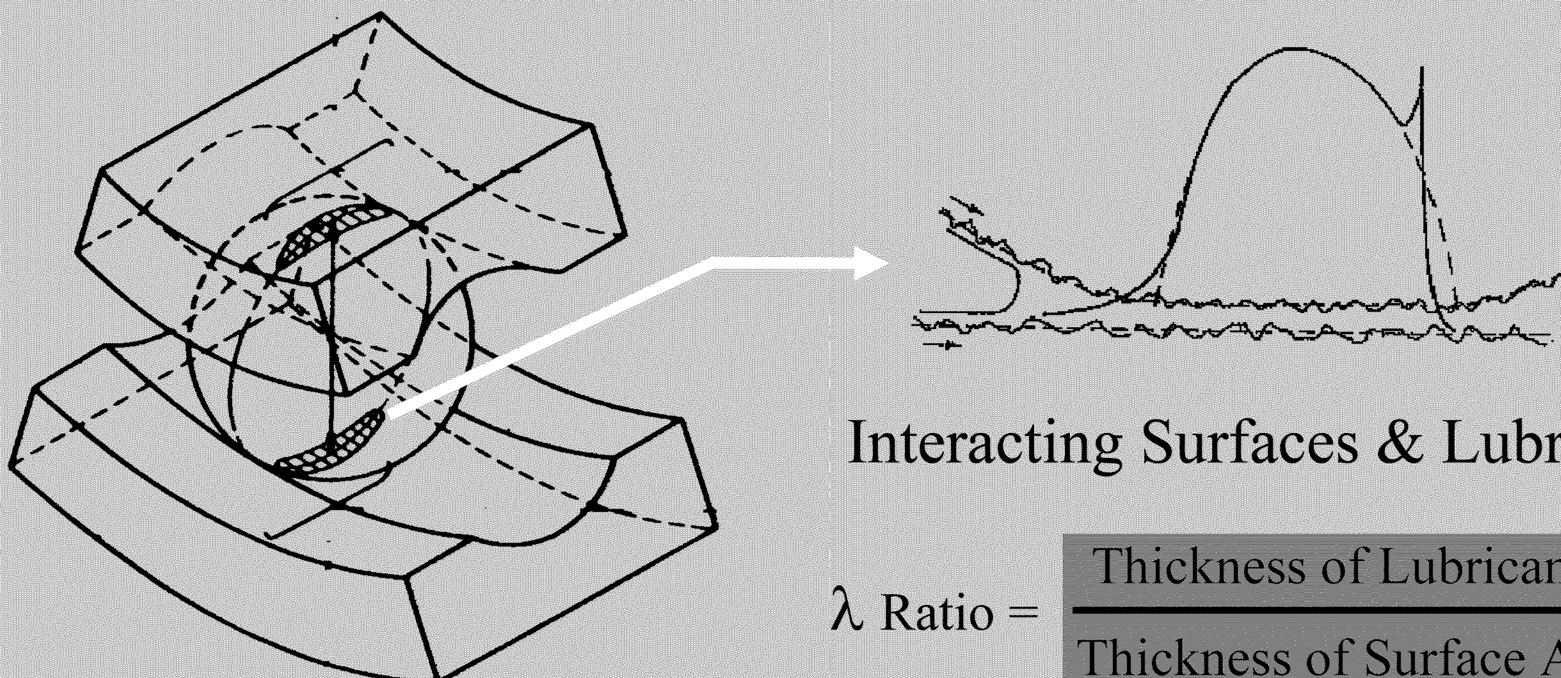


Elliptical Contact
Between Ball & Race



The Bearing / Lubricant System

The Tribology of a Bearing: Synergy Between Material, Lubricant & Design - λ Ratio.



Interacting Surfaces & Lubricant:

$$\lambda \text{ Ratio} = \frac{\text{Thickness of Lubricant Film}}{\text{Thickness of Surface Asperity}}$$

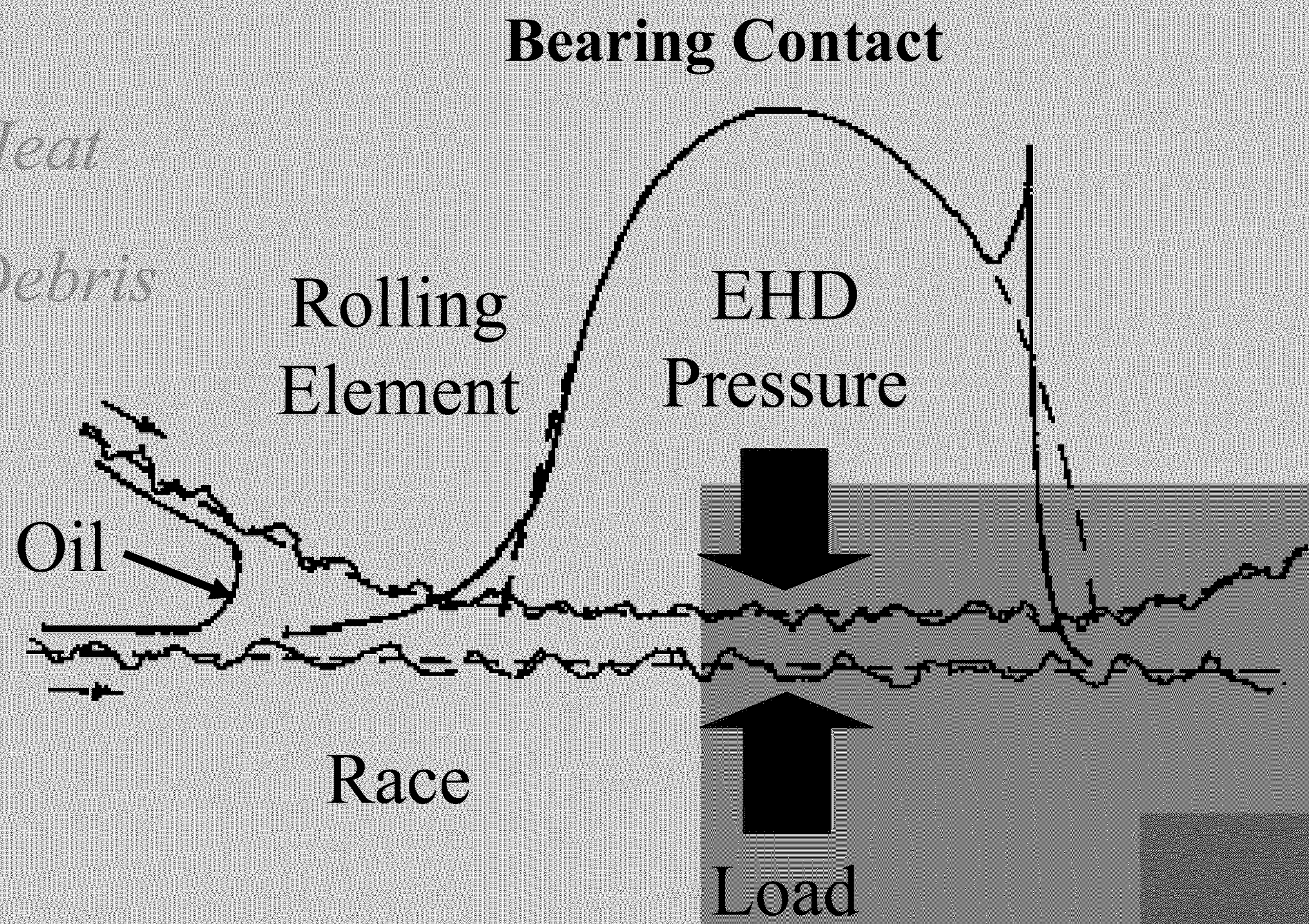
λ Ratio > 1 Full EHD Lubrication

λ Ratio < 1 Boundary Lubrication

The Bearing / Lubricant System

Lubricant: The Life Blood of an Engine With Many Functions:

- Lubricate
- Remove Heat
- Remove Debris

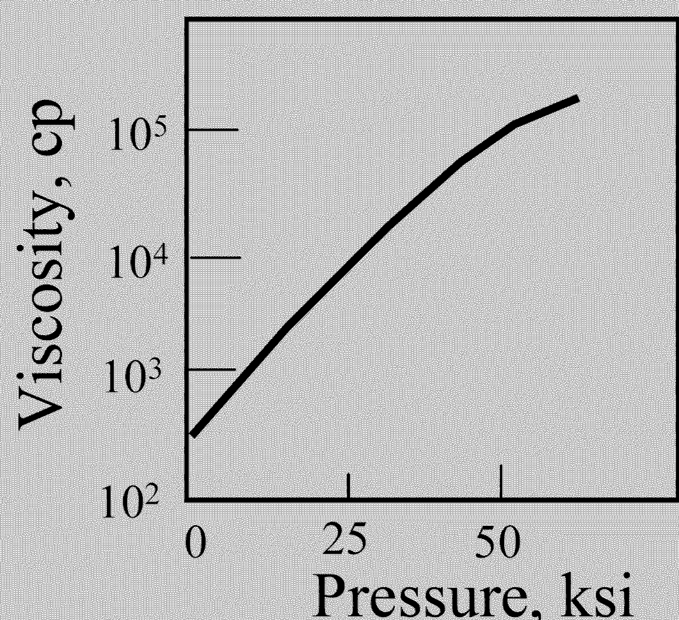


The Bearing / Lubricant System

Lubricating Characteristics

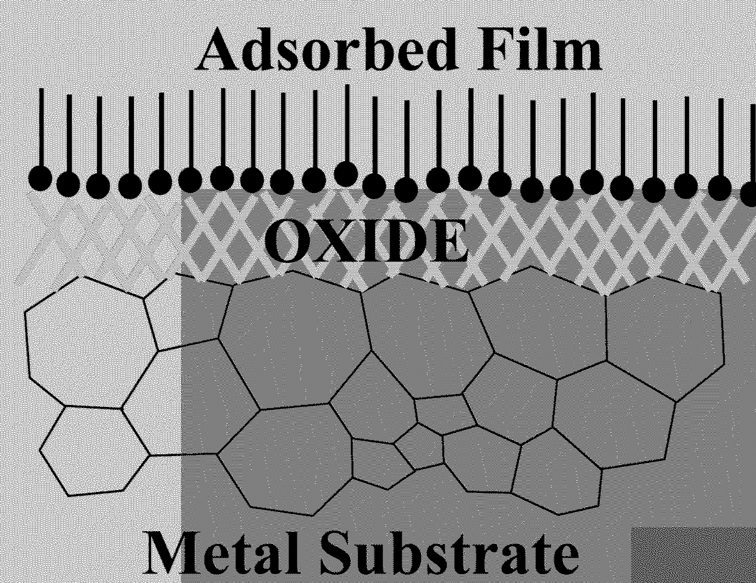
Pressure - Viscosity:

The Secret to Load Bearing Capability



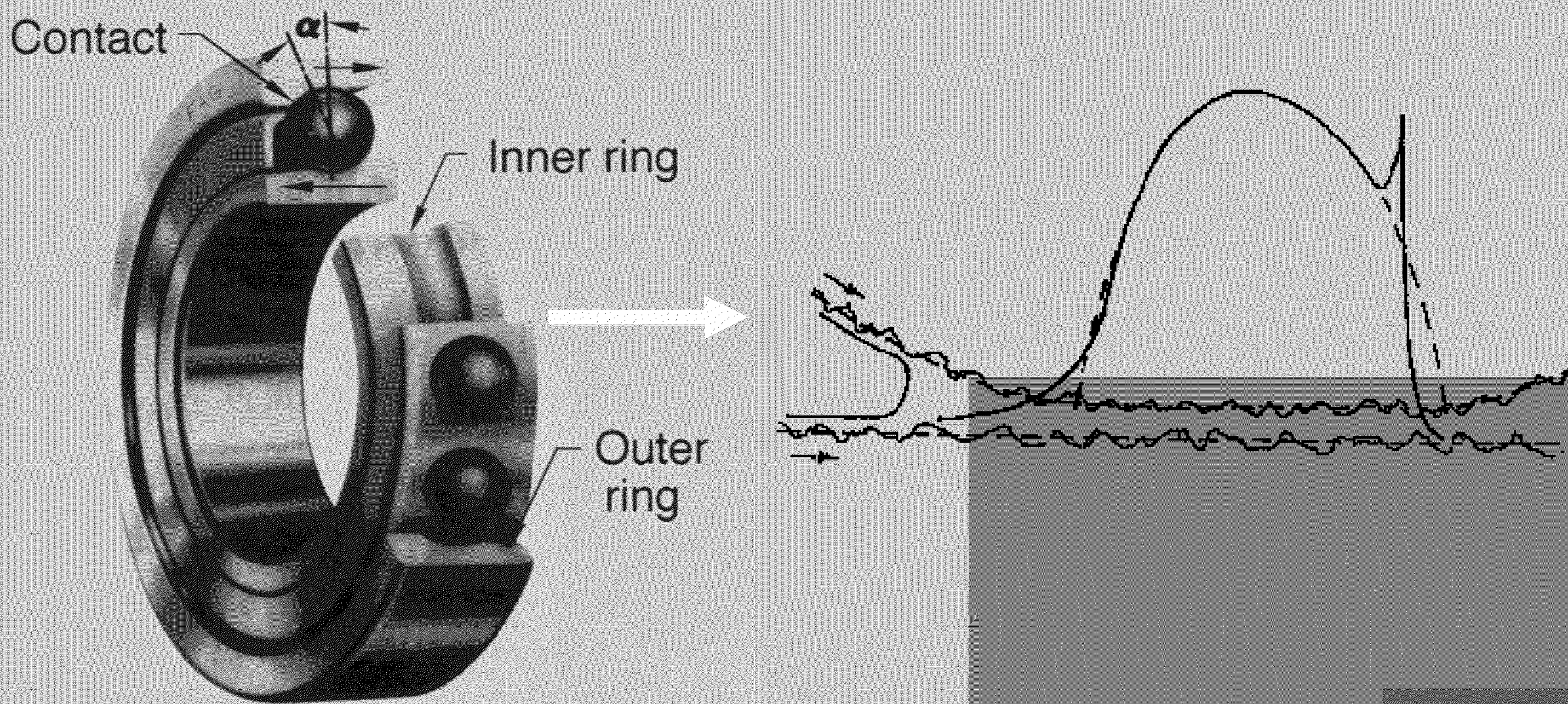
Anti-wear Additive:

The Secret to Boundary Lubrication



The Bearing / Lubricant System

In Summary, a Bearing Is Not a Component. It Is a System. And So, There Is Much to Consider...

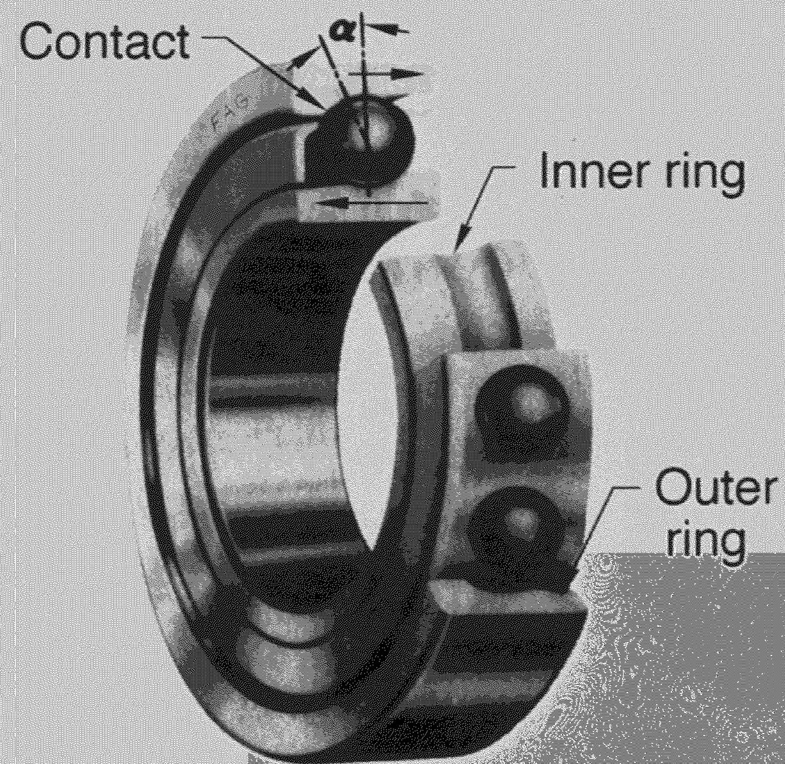


Advanced Bearing Materials & Lubes

Bearing Material Requirements

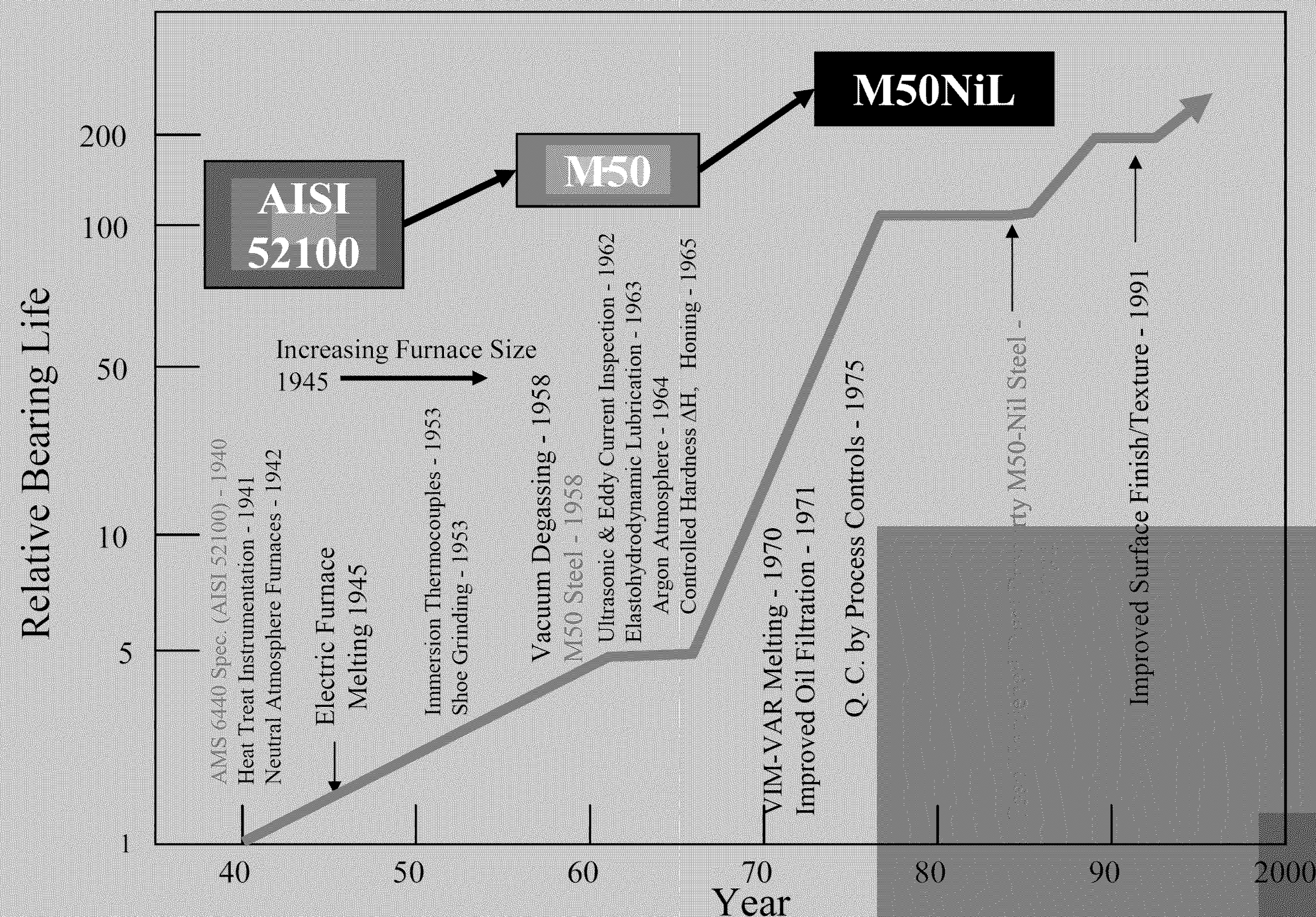
Bearing Material Needs:

- Hardness
- Strength
- Toughness
- Corrosion Resistance
- Wear Resistance
- Temperature Capability



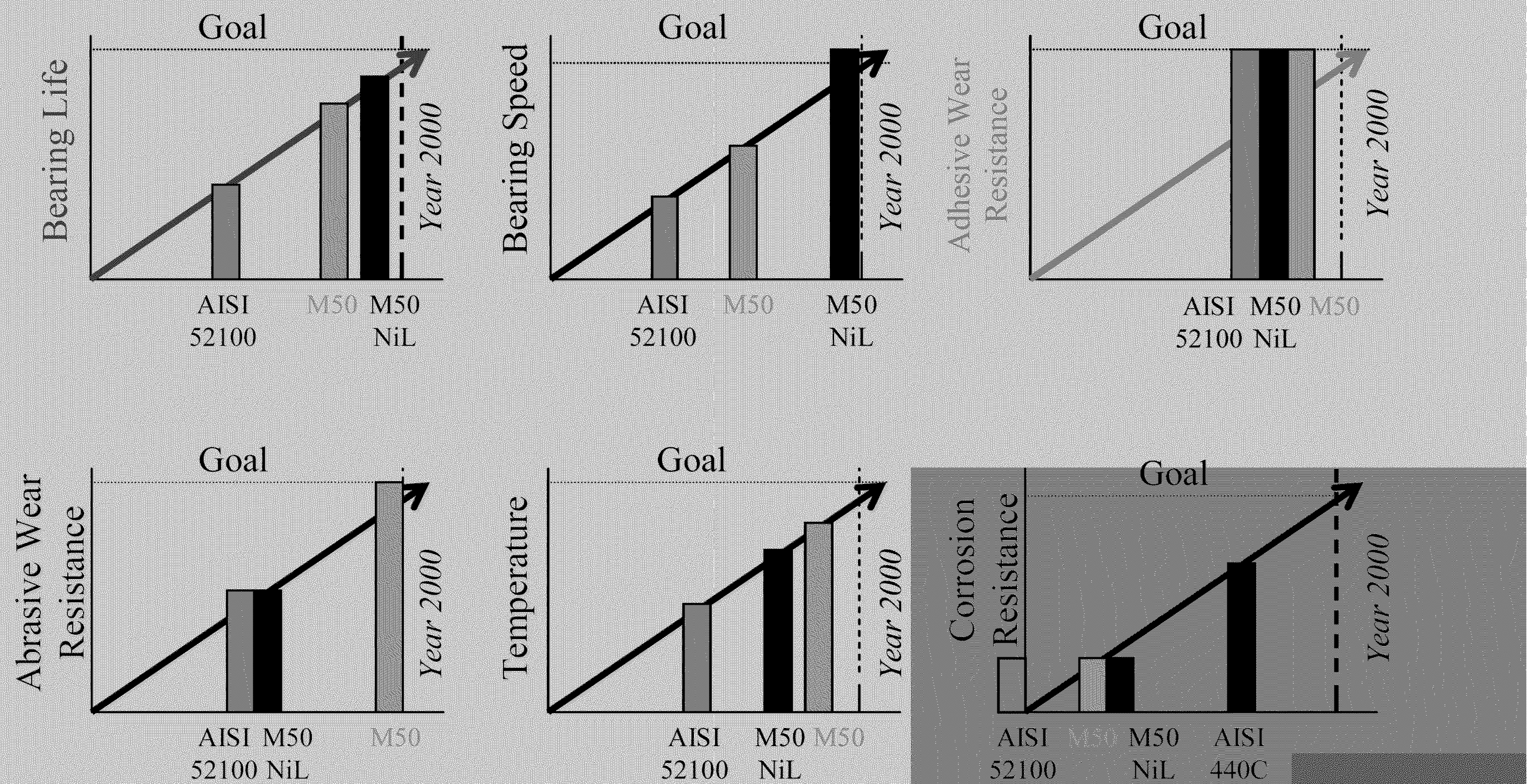
Aerospace Bearing Materials

Evolution of Bearing Materials From ~1940



Aerospace Bearing Materials

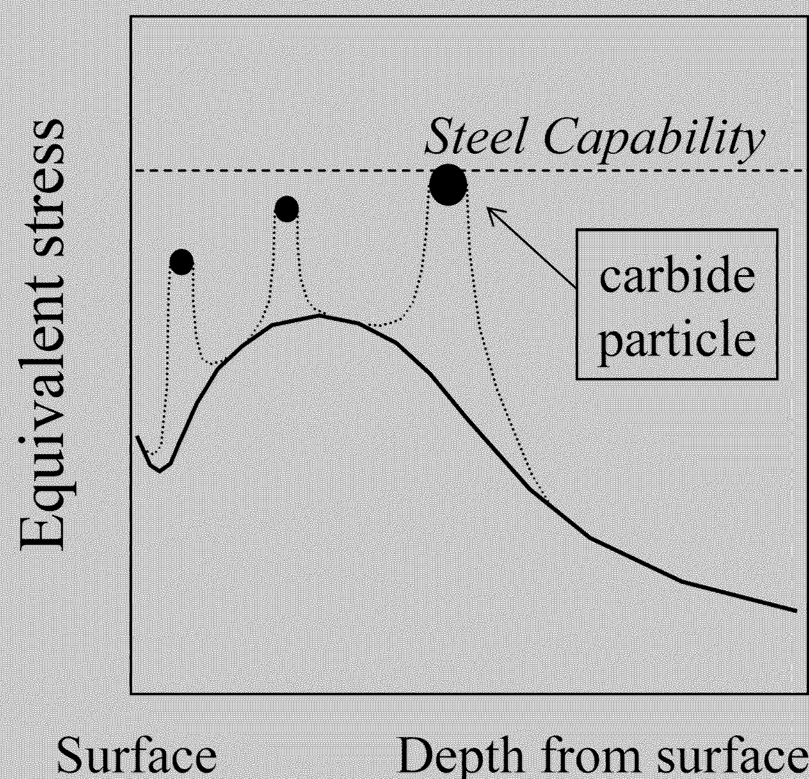
Bearing Material Requirements Into the Next Millennium



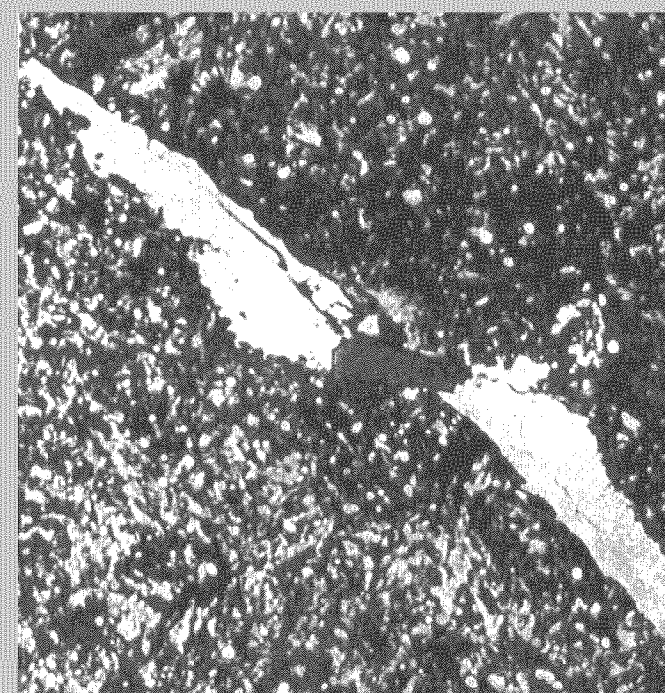
Aerospace Bearing Materials

Influence of Large Carbides on Bearing Life

Carbides Are Stress Risers



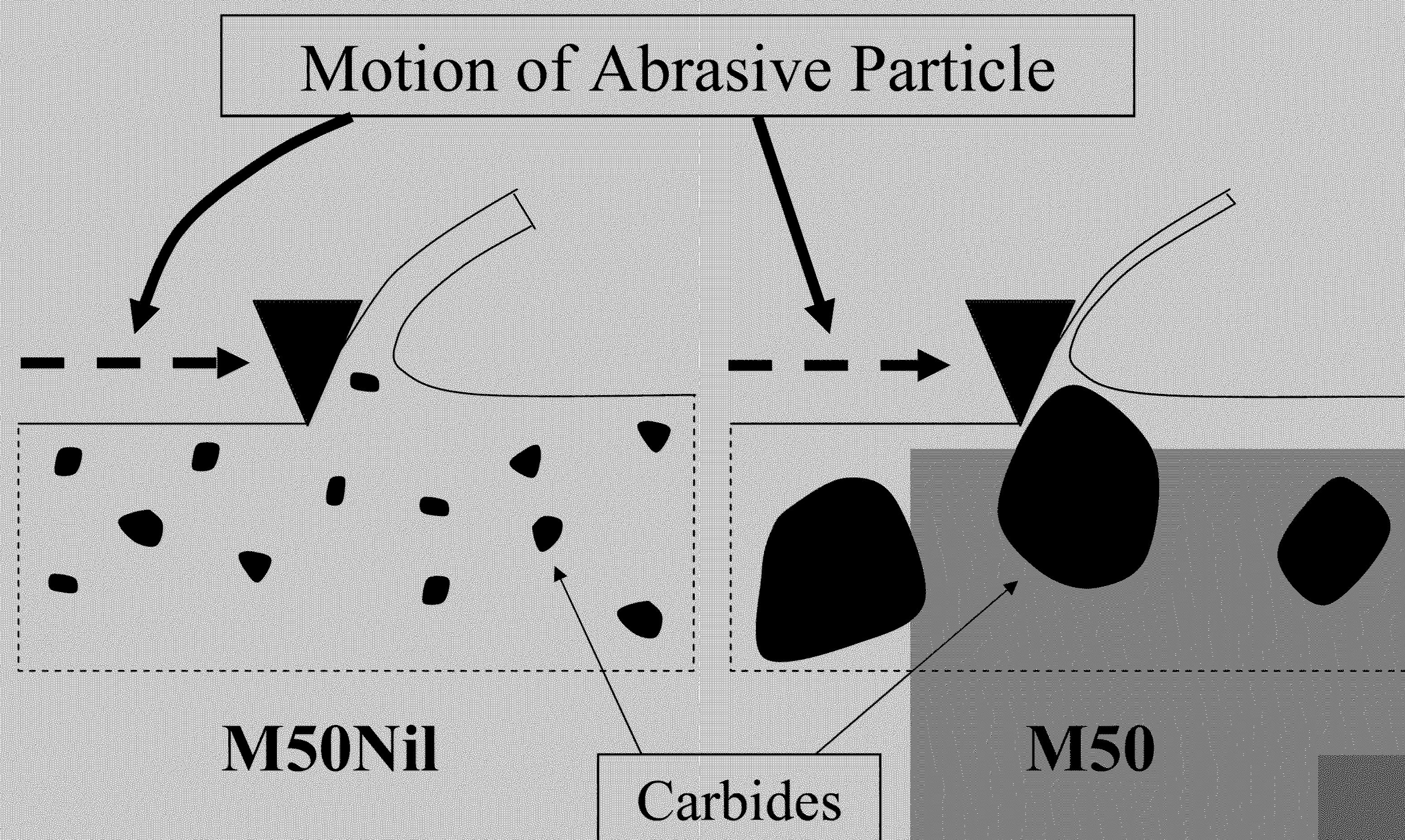
Cracks From Stress Risers



"Butterfly Crack"

Aerospace Bearing Materials

Influence of Carbide Size on Abrasive Wear Resistance



Aerospace Bearing Materials

Bearing Materials Vision Into the Next Millennium

Hybrid Bearings: Dissimilar Race / Rolling Element Material

Application

Today

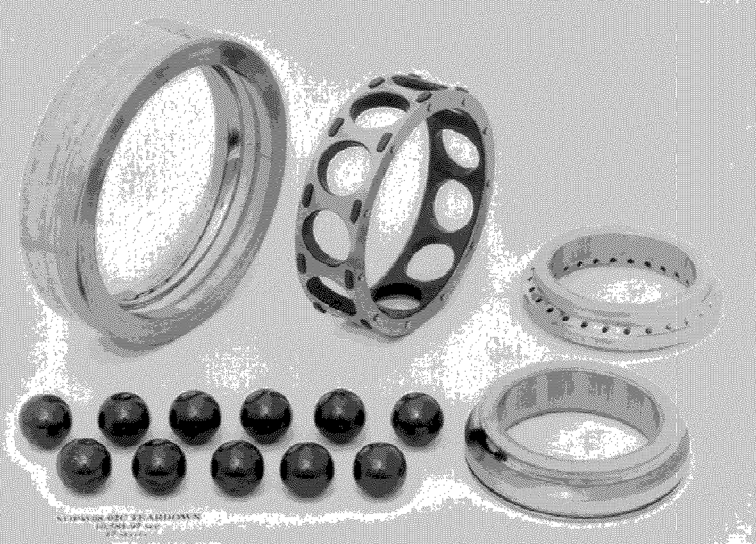
Future

	Low Speed Bearings	High Speed Bearings
Application	< 2.2 mDN	> 2.2 mDN
Today	M50 Steel	M50 NiL Steel
Future	Through Hardened **Stainless Steel Rings** & Si_3N_4 Rolling Elements	Case Hardened **Stainless Steel Rings** & Si_3N_4 Rolling Elements

Aerospace Bearing Materials

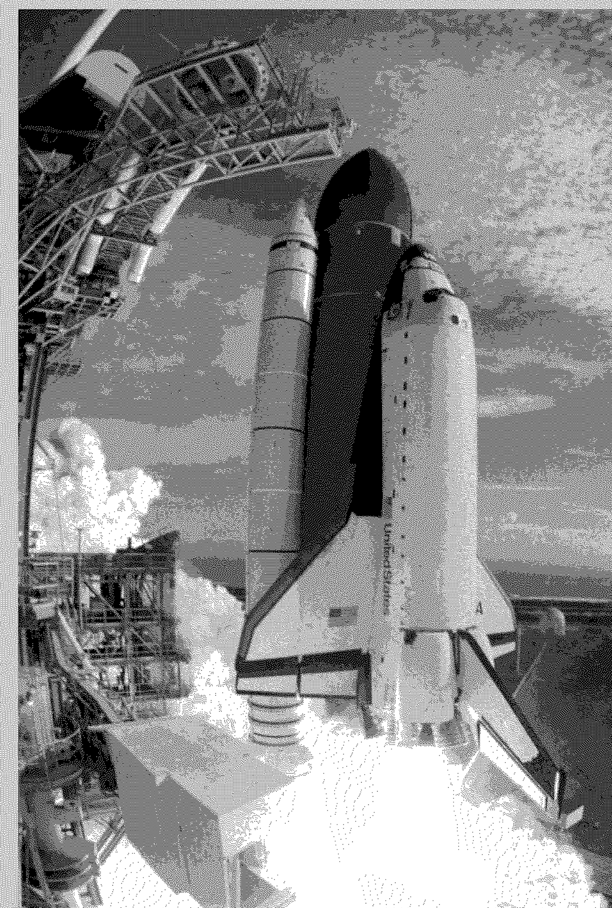
Advanced Si_3N_4 Rolling Elements

Si_3N_4 Hybrid Bearing



Material-Lubricant Synergy was CRITICAL to Success !

The Ultimate Test

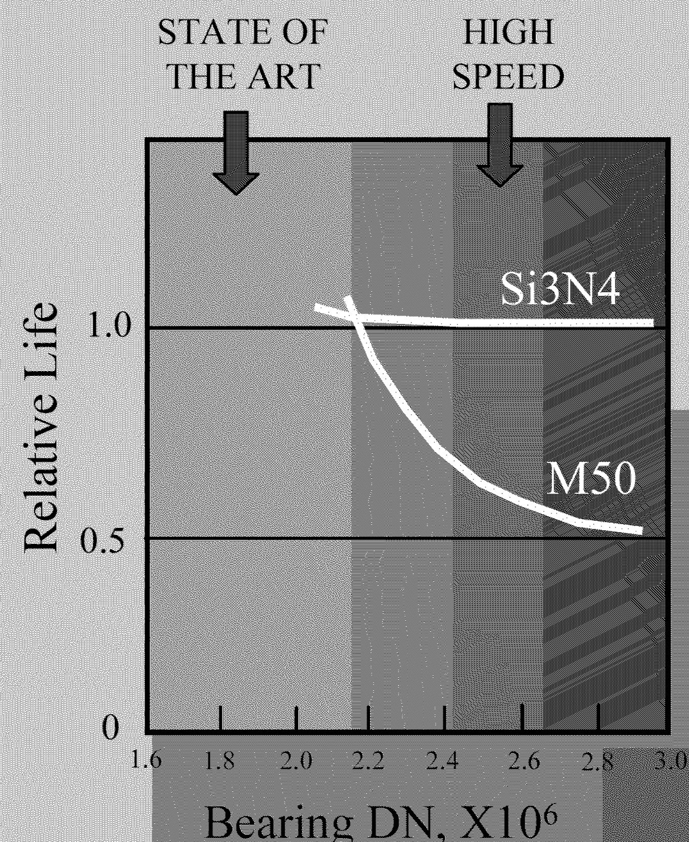


Aerospace Bearing Materials

Si_3N_4 Hybrid Bearings Enable High Speeds

Pyrowear 675 / Si_3N_4 Full Scale Bearing Successfully Ran at 675°F (357°C)

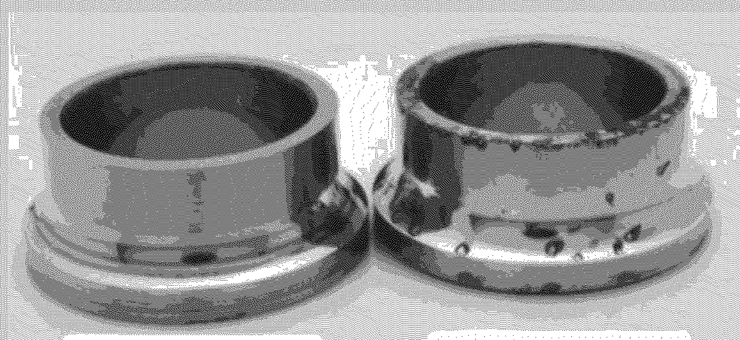
Si_3N_4 Lowers Ball Centrifugal Loads & Frictional Heating



Aerospace Bearing Materials

Bearing Materials Vision Into the Next Millennium:
Low Speed Application - Opportunities

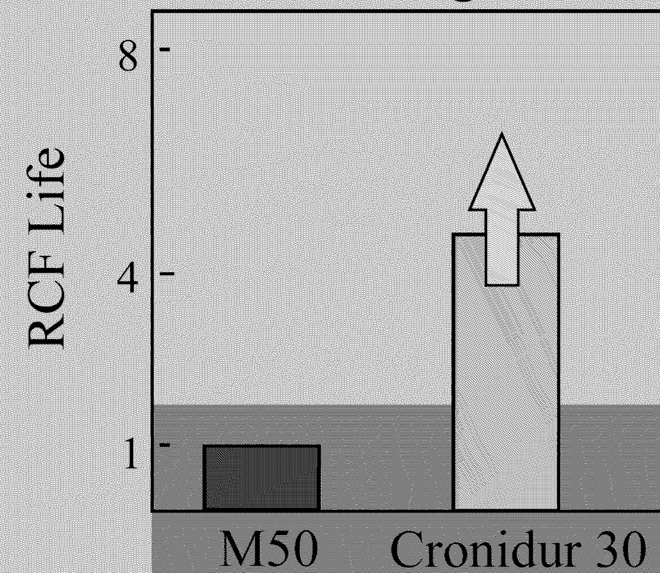
Cronidur 30 Corrosion
Resistance100X >
AISI 440C Stainless Steel



Cronidur 30 | AISI 440C

Nitrogen + Low Carbon Boosts
Corrosion Resistance of the Steel

Improved Rolling
Contact Fatigue Life



Absence of Coarse Carbide Stringers
+ Compressive Residual Stress
→Increased Bearing Life

Aerospace Bearing Materials

Bearing Materials Vision Into the Next Millennium:

Low Speed Application - Status

- **Two New Through-Hardened Nitrogen Alloyed Martensitic Stainless Steels Show Promise:**

Alloy	AMS#	Fe	Cr	Mo	V	N	C
Cronidur 30	5898	Bal.	15.0	1.0	0.0	0.35	0.33
XD15NW	5925	Bal.	15.8	1.7	0.3	0.20	0.41

- **Sub-scale Bearing Rig Testing Showed Improved Bearing Lives AND 100X Corrosion Resistance Over M50 Steel**
- **Full-scale Bearing Rig Testing of Cronidur 30 Showed Cage Rub and Undesirable Tribological Load Path Interaction.**
- ***Need for Bearing Materials-Lubrication Synergy Most Evident for Stainless Bearing Steels***

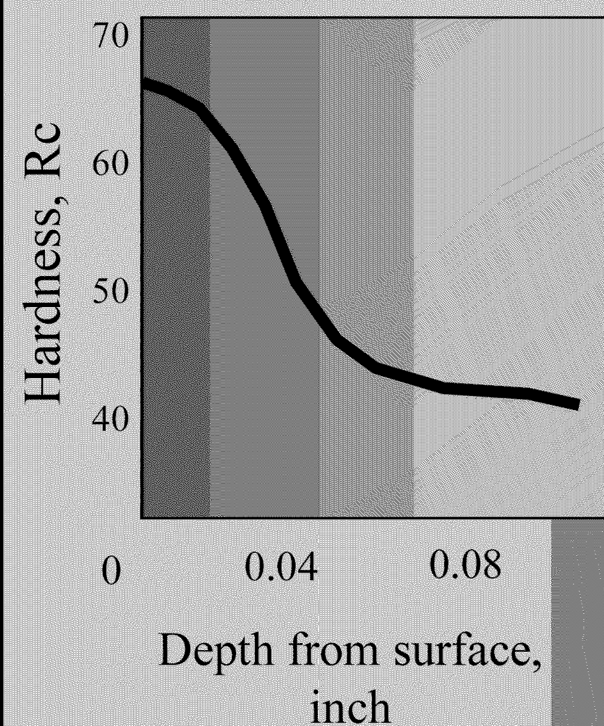
Aerospace Bearing Materials

Bearing Materials Vision Into the Next Millennium:

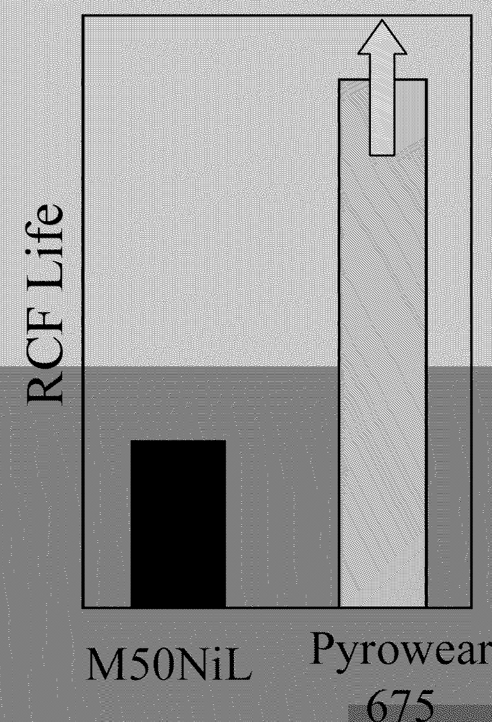
High Speed Application - Opportunities

Microstructure of Carburized Case

Hardness Profile



Improved Rolling Contact Fatigue Life



Aerospace Bearing Materials

Bearing Materials Vision Into the Next Millennium:

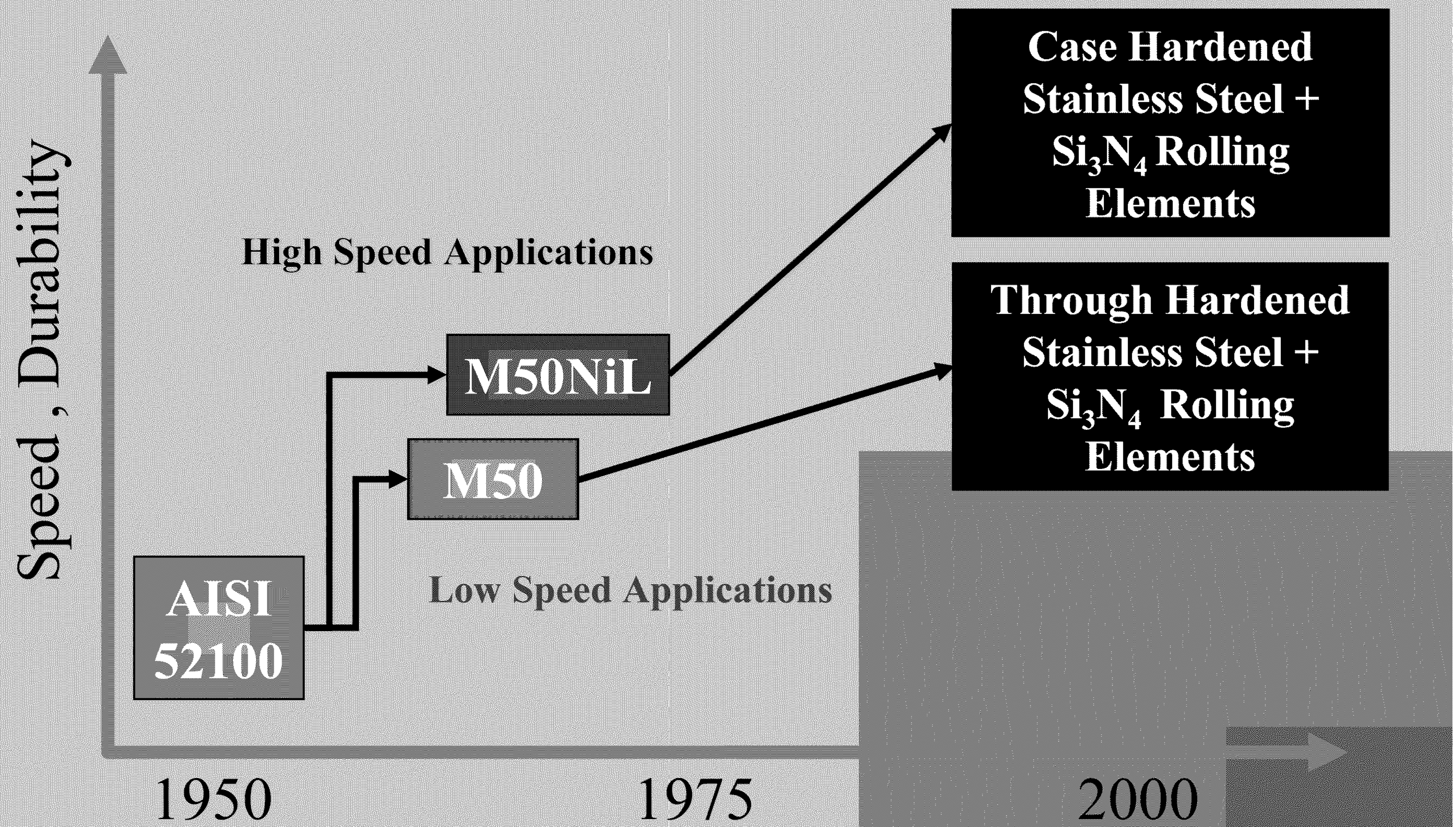
High Speed Application - Status

- Sub-scale Bearing Rig Testing Showed Improved Bearing Lives AND 10X Corrosion Resistance Over M50 Steel
- Full-scale Pyrowear 675/Si_3N_4 Bearing Rig Testing at Elevated Temperature Showed Improved Performance Over M50 Steel Bearings.
- **Cage Rub and Undesirable Tribological Load Path Interaction of All Stainless Steel Bearing Remain a Concern.**
- **Again, Need for Bearing Materials-lubrication Synergy Most Evident for Stainless Bearing Steels**

Aerospace Bearing Materials

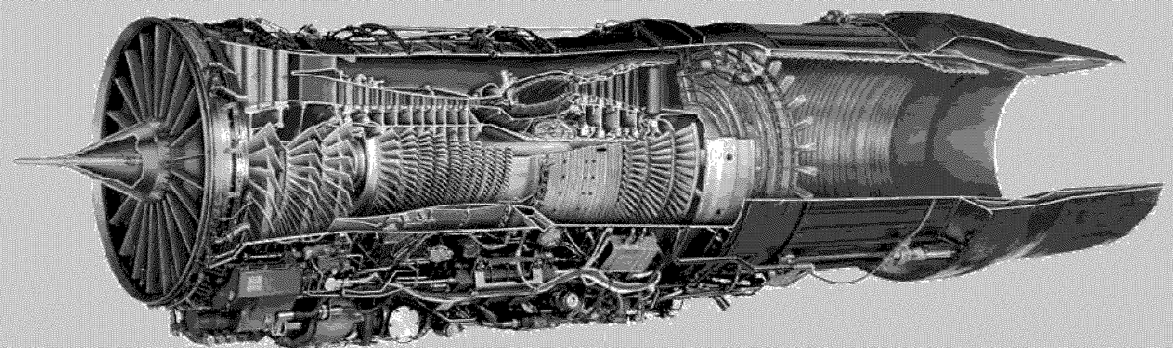
Summary of Bearing Materials Evolution.

Need for Material-Lubrication Synergy a Must !!!



Aircraft Turbine Engine Lubricants

Gas Turbine Challenges For Ester Based Lubricants



Desire for Increased Thrust to Weight Ratios:

- Higher Compression Ratios
- Higher Combustion Temperatures
- Higher Turbine Inlet Temperatures
- Reduced Cooling Air
- Higher Rotor and Gear Speeds

Consequence: Increased Thermal and Tribological Demands on the Engine Lubrication System

Aircraft Turbine Engine Lubricants

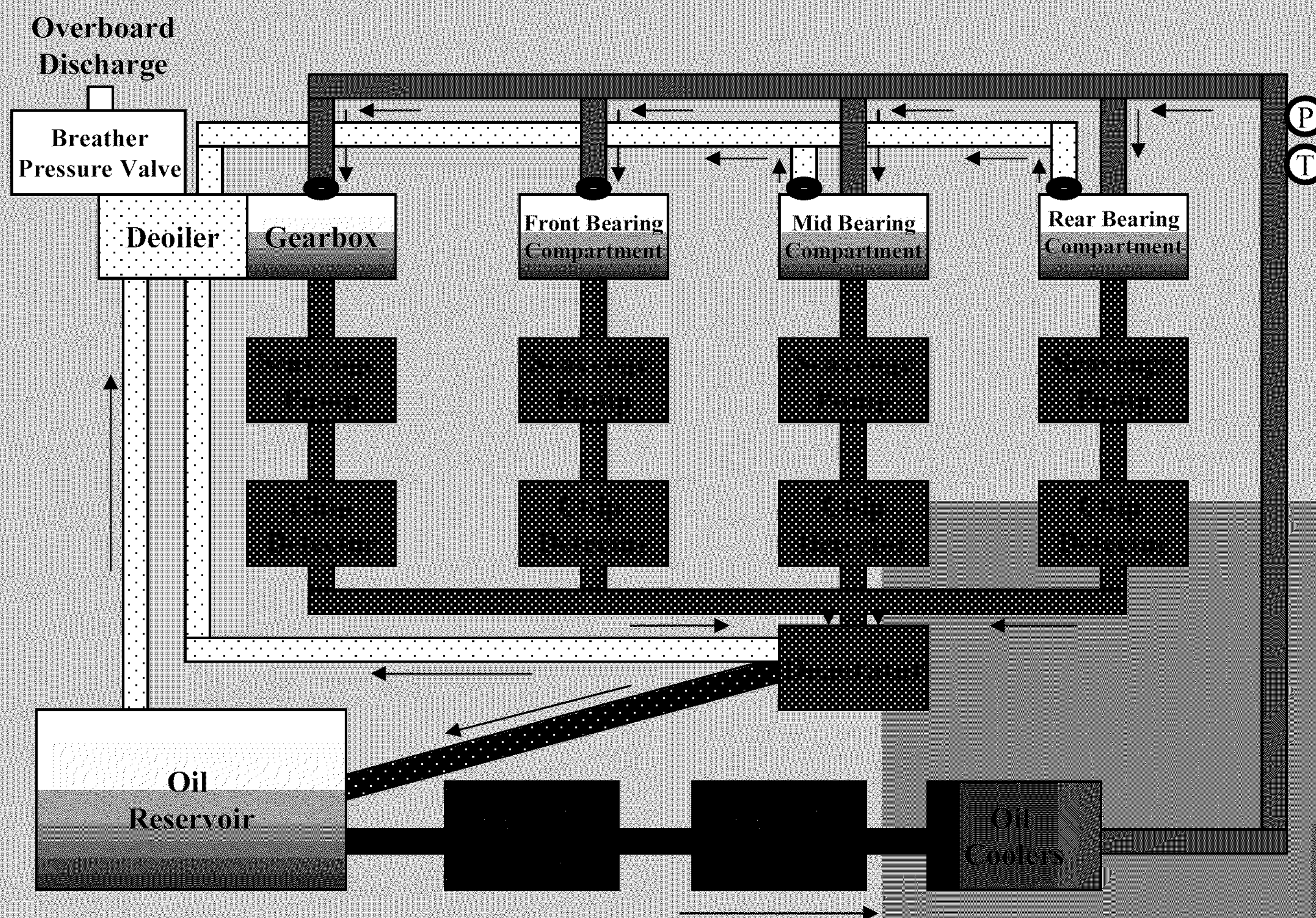
Lubricant Functions / Requirements

- ✓ **Reduce FRICTION and WEAR of Bearings, Gears and Other Rotating Components**
- ✓ **Cool Lubrication System Components**
- ✓ **Transport Debris Away From Lubrication System Components**
- ✓ **Compatible With Metallic and Non-metallic Lubrication System Components**

Aircraft Turbine Engine Lubricants

Engine Hardware Lubrication System:

Many Micro-Environments



Aircraft Turbine Engine Lubricants

Critical Properties Of The Lubricant

Viscosity & Density	- Heat Generation - Lubrication System Pressure - Component Size & System Weight - Pump-ability
Vapor Pressure	- Compartment Pressure & Operability - Fluid Losses - Pump Performance
Foaming Characteristics	- Engine Pump Operability (Cavitation) - Tank Size - Component Speeds - Lubricant Cooling Capacity
Specific Heat & Thermal Conductivity	- Heat Exchanger Size

Aircraft Turbine Engine Lubricants

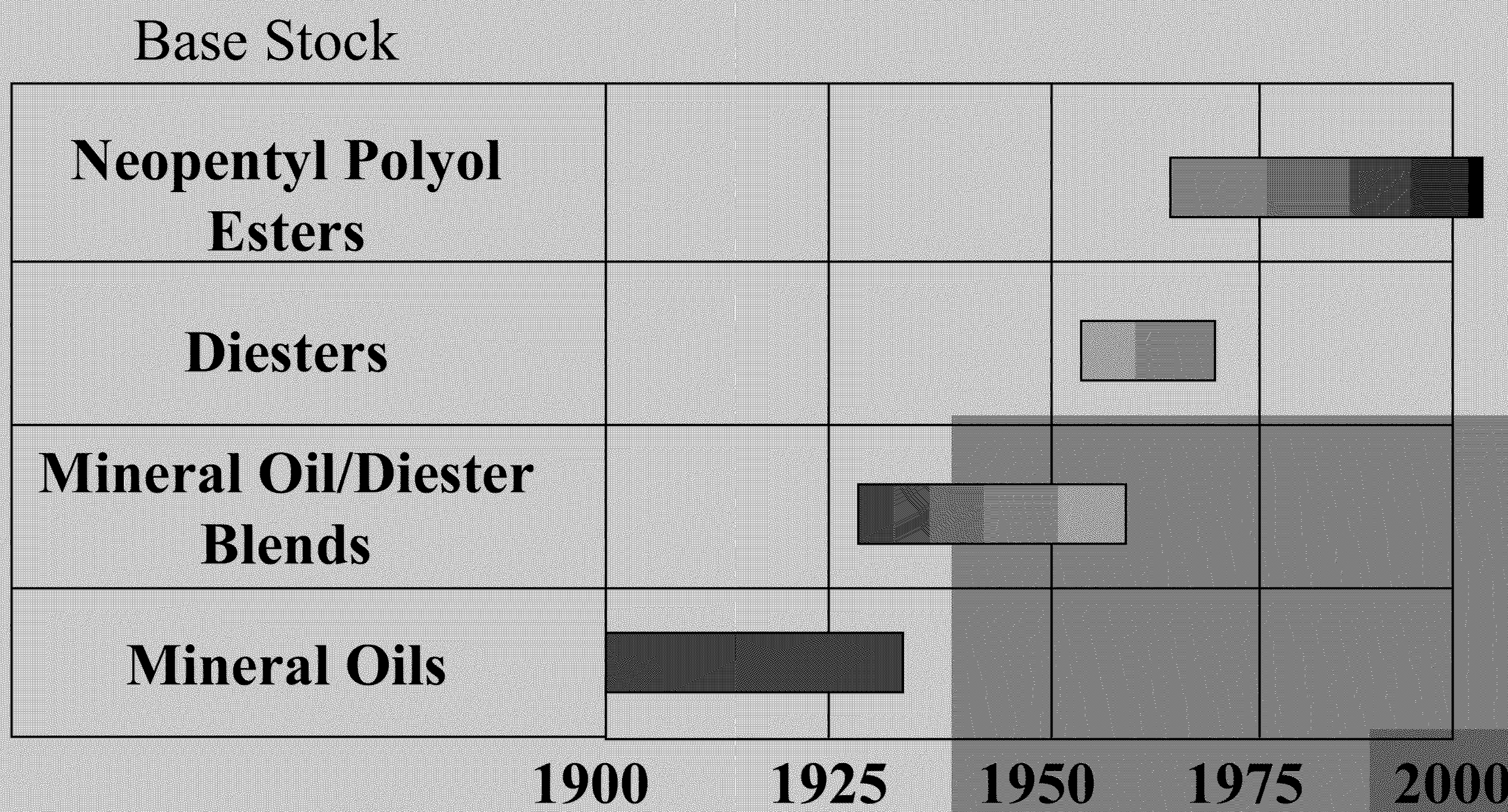
Critical Properties Of The Lubricant

Thermal & Oxidative Stability	- Bearing Operating Temperatures - Coking Resistance - System Weight
Auto-Ignition Temperature	- Bearing Compartment Operating Temperature - System Weight
Tribological Performance	- Rotating Components Speed, Size, & Materials - Lubricant Cooling Capacity
Elastomer / Material Compatibility	- System Integrity

Aircraft Turbine Engine Lubricants

History Of Lubricants:

"In the Beginning, There Were Mineral Oils"



Aircraft Turbine Engine Lubricants

Capabilities of Oils Relative to Mineral Oils

Diester/Polyol Esters

↑

Mineral Oils

- ✓ **Higher Thermal-Oxidative Stability**
- ✓ **Improved Tribological Performance**
- ✓ **Better Viscosity Index**

Neopentyl Polyol Esters

↑

Diesters

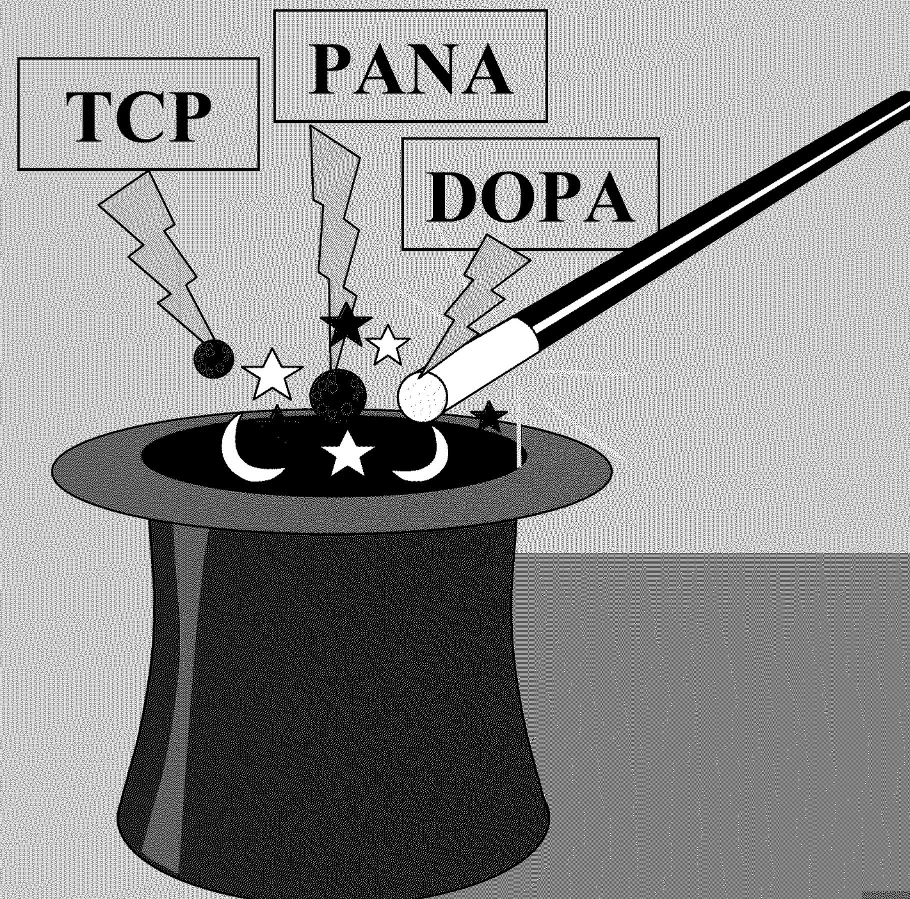
- ✓ **More Thermal Stability Improvements**
  - **Bulk Oxidative Stability**
  - **Liquid & Vapor Coking Resistance**

Increased *Temperature* Capability →

Aircraft Turbine Engine Lubricants

Oil Properties Are Strongly Influenced by Additives

- Thermal - Oxidative Stability
- Tribological Performance



Aircraft Turbine Engine Lubricants

Impact of Thermal-Oxidative Stability

Engine Performance
- Thrust-to-Weight Ratio
- Buffer Cooler System Requirements

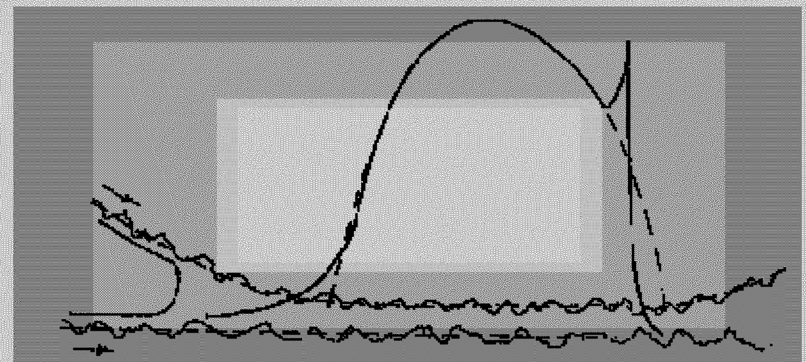
Engine Durability
- Bearing and Gear Life
- Maintenance Requirements

= $$

Engine Weight and Manufacturing Costs
- Number, Size & Type of Heat Exchangers
- Heat Shielding & Insulation Requirements

Aircraft Turbine Engine Lubricants

Bearing Lubrication



Primary Mechanism of Bearing Lubrication

- ***Lubricant Film Formation in Response to Bearing Contact Interacting Dynamics***
- ***Lubricant Film Serves to Physically Keep Surfaces Apart***

Elasto-Hydrodynamic Lubrication

Function of Base-stock Chemistry:
Temperature-Viscosity &
Pressure-Viscosity Characteristics

Boundary Lubrication

Function of Additives:
Anti-wear Additive &
Other Competing Chemistries

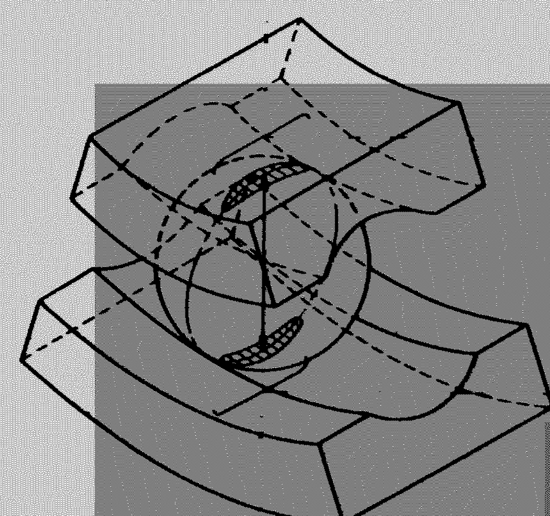
Aircraft Turbine Engine Lubricants

Elasto-Hydrodynamic Lubrication - Basic Principles

Elasto-Hydrodynamic (EHD) Lubrication Cushions Contacts During Operation

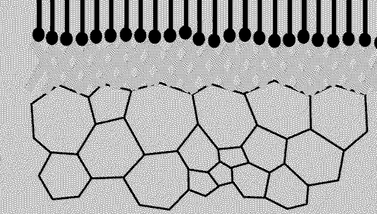
Tribological Performance Governed By:

- ✓ **Lubricant Pressure - Viscosity Characteristics**
- ✓ **Lubricant Temperature - Viscosity Characteristics**
- ✓ **Contact Geometry**
- ✓ **Contact Entraining Velocity**
- ✓ **Contact Loads**
- ✓ **Contact Surface Finish**
- ✓ **Contact Temperature**



Aircraft Turbine Engine Lubricants

Boundary Lubrication - Basic Principles



Adhesive Wear Defended by Boundary Lubrication

- **Occurs During: Start-up, Shut-down & High G Maneuvers**
- **Molecular Boundary Layers Form Last Line of Defense**
- **Influenced by Materials, Surface Treatments & Roughness**

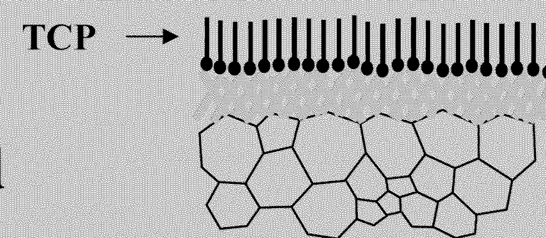
Anti-wear Additive Used to Mitigate Adhesive Wear

- **Additive Chemically Reacts With Bearing Surface to Form Chemically Adsorbed Film**
- **Required When Bearing Contact Areas [illegible] Maintenance of Effective Lubricant Film [illegible]**
- **Additive Film Protect Bearing Surface [illegible] Wear**

Aircraft Turbine Engine Lubricants

Boundary Lubrication - Tricresyl Phosphate (TCP)

TCP In All Currently Approved Aircraft Lubricant Formulations



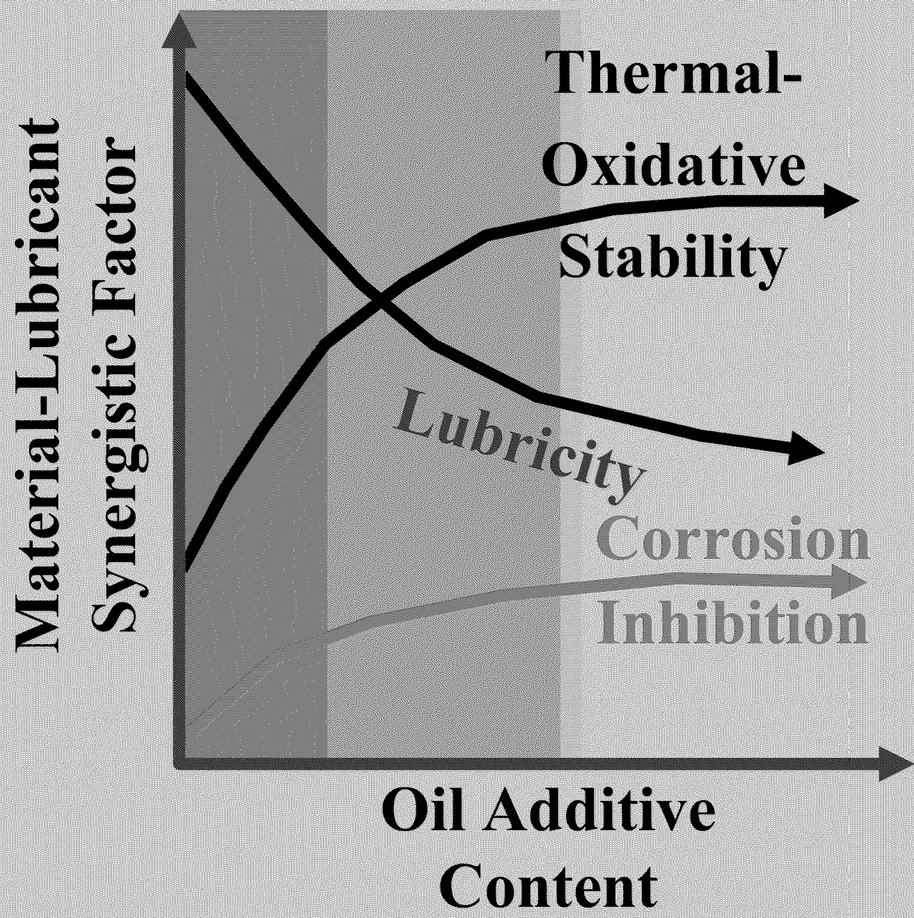
Properties/Characteristics:

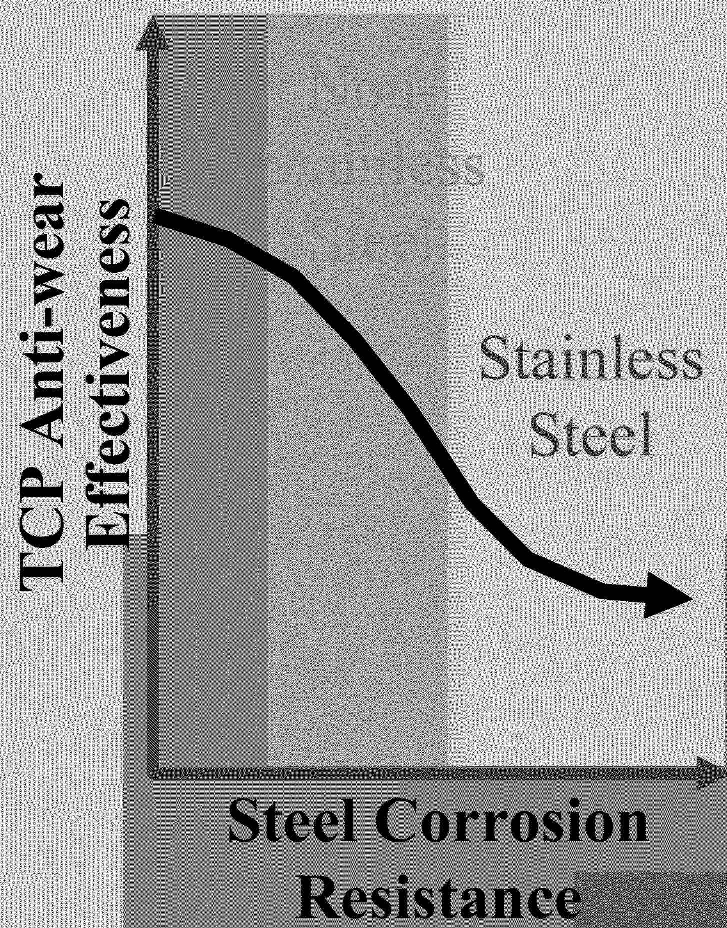
- **Practically Colorless, Odorless Liquid**
- **Boiling Point 420°C (788°F)**
- **Non-volatile, Combustible**
- **Typically Blended in Oil at 1-3 Wt. %**

- **Reacts Readily With Current Bearing Steels (M50, etc.)**
- **Does Not React Easily With Stainless Bearing Steels**
- **Other Chemistries Being Investigated Under a USAF SBIR**

Aircraft Turbine Engine Lubricants

Material-Lubricant Synergistic Factors





Aircraft Turbine Engine Lubricants

Material-Lubricant Synergistic Factors

Enabling Technology Required For Improved Bearings:

Boundary Lubrication of Corrosion Resistant Bearing Steals

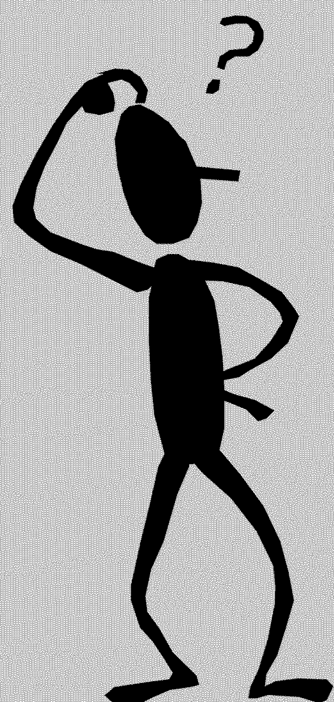
Potential Approaches:

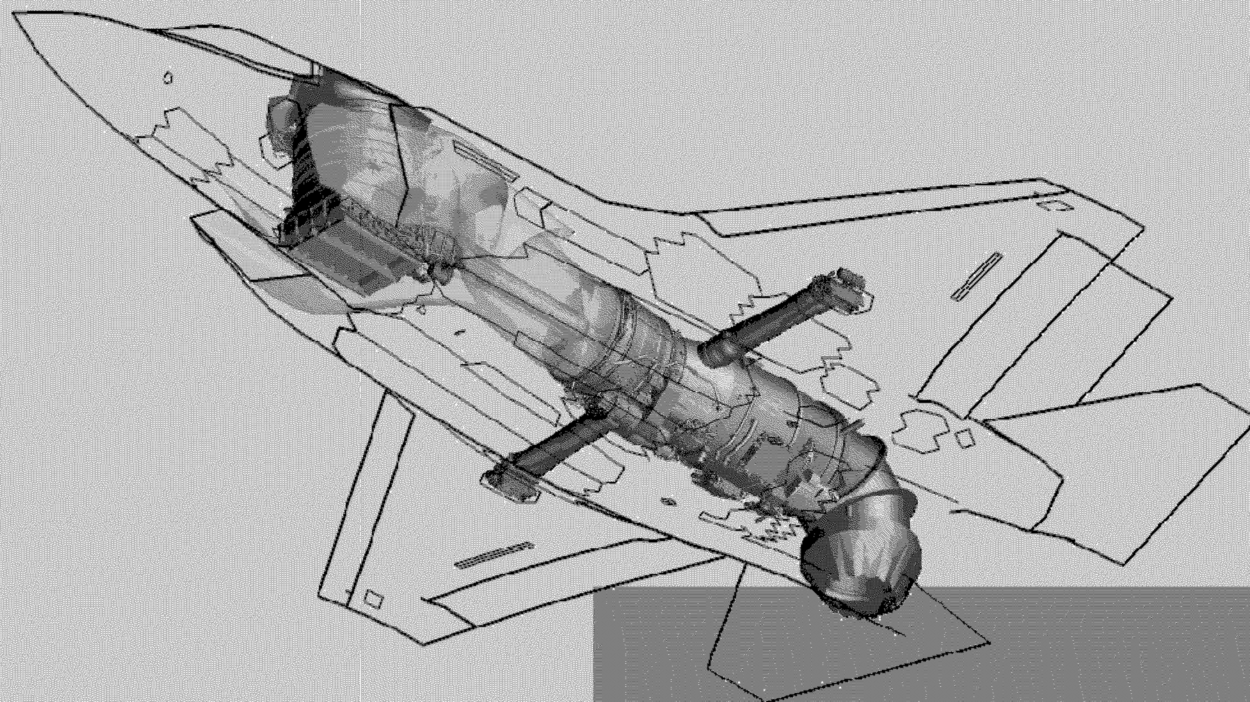
- **Use Si_3N_4 Rolling Elements - Hybrid Bearings**
- **More Chemically Reactive Anti-Wear Additives**
- **Bearing Surface Treatments To Increase Reactivity To TCP**

Synergy Between Bearing Materia
Tribological Properties a Necessity fo
Gas Turbine Engine Mechanical Com
the Next Millennium

Material / Lubricant Synergism

Questions??





SEALS FOR HTS OILS

16 June 2004

Testing Performed by DuPont Dow Elastomers

Alan Fletcher

Program Manager

Materials & Manufacturing Directorate

Air Force Research Laboratory

Overview of presentation

- Gas turbine design & technology trends
- Elastomers evaluated
- Lube oils evaluated
- Test protocol
- Test results in jet oils
- Best-in-class fluoroelastomers and perfluoro-elastomers for gas turbine engine service
- Summary

Design & Technology trends

- Higher thrust, hotter, more efficient engines
- Reductions in weight, noise, emissions and fuel consumption
- Improved reliability & maintainability
- Longer intervals between engine overhauls (time on wing)

Design & Technology Trends (cont.)

- Rising temperatures
  - 260-285°C (500-550°F) soak-back
  - lube oils running hotter
- Aggressive inhibitor packages are now prevalent
  - will require better “base resistant” fluoroelastomers, or upgrade to perfluoroelastomers (for service >200°C)

Objective of our study

Characterize properties and property retention of selected fluoroelastomers and perfluoroelastomers in various commercial gas turbine engine oils in order to ascertain compatibility and recommend best-in-class offering

Fluoroelastomers Evaluated

Polymer	Composition	% Fluorine
• Viton® A601C	VF_2/HFP	66.0
• Viton® GBL-S	VF_2/HFP/TFE/CS	67.0
• Viton® GF-S	VF_2/HFP/TFE/CS	69.5
• Viton® GLT-S	VF_2/TFE/PMVE/CS	64.0
• Viton® GBLT-S	VF_2/TFE/PMVE/CS	67.0
• Viton® GFLT-S	VF_2/TFE/PMVE/CS	66.5
• Viton® ETP-S	E/TFE/PMVE/CS	67.0

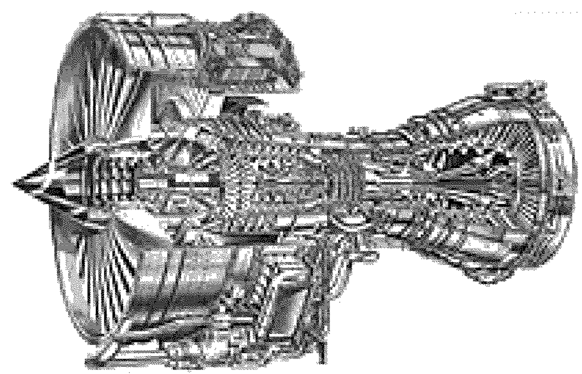
- A-601C (AMS 7276 / MIL-R-83248)
- GLT-S (AMS-R-83485)

Perfluoroelastomers Evaluated

- Kalrez® 4079AMS – 75 durometer, meets AMS 7257C
- Kalrez® 6375 – 75 durometer, general purpose, broad chemical resistance - designed for CPI market
- KLX-99003 – experimental product, 75 durometer, broad chemical resistance, high thermal, low comp. set, improved stress relaxation and temp. cycling
- KLX-03002 – experimental product, 75 durometer, high modulus, high thermal, low comp. set
- KLX-02001 – experimental product, 90 durometer, high modulus

All compositions consist of TFE/PMVE/CSM (typically 72-73% fluorine)

Gas Turbine Engine Oils



Basic Components of Synthetic Jet Oil:

- polyol ester base stock
- antiwear (load carrying) additive
- antioxidants (aryl hindered amine type)
- metal passivators-deactivators
- defoamant (silicone type)

Gas Turbine Oils Evaluated

Standard Oils

- **Air BP Turbo Oil 2380**
- **Mobil Jet Oil II**

HTS Oils

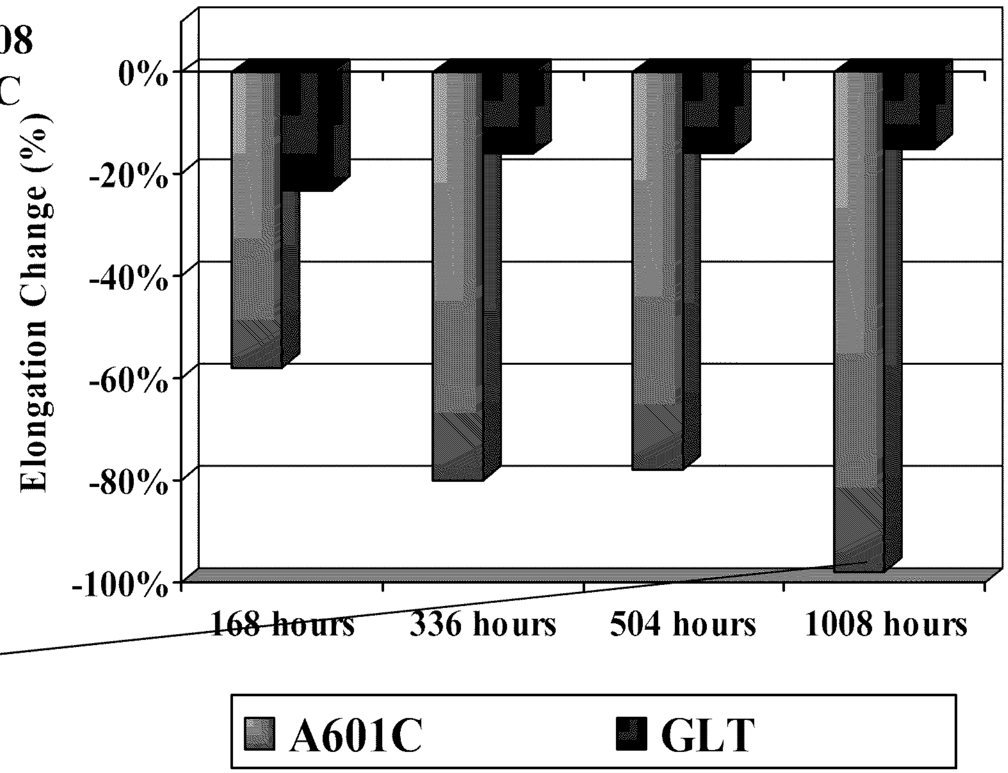
- **Air BP Turbo Oil 2197**
- **Mobil Jet Oil 254**
- **Mobil Jet Oil 291**
- **Aeroshell 560**

Reference Oil 300
(HTS-type)

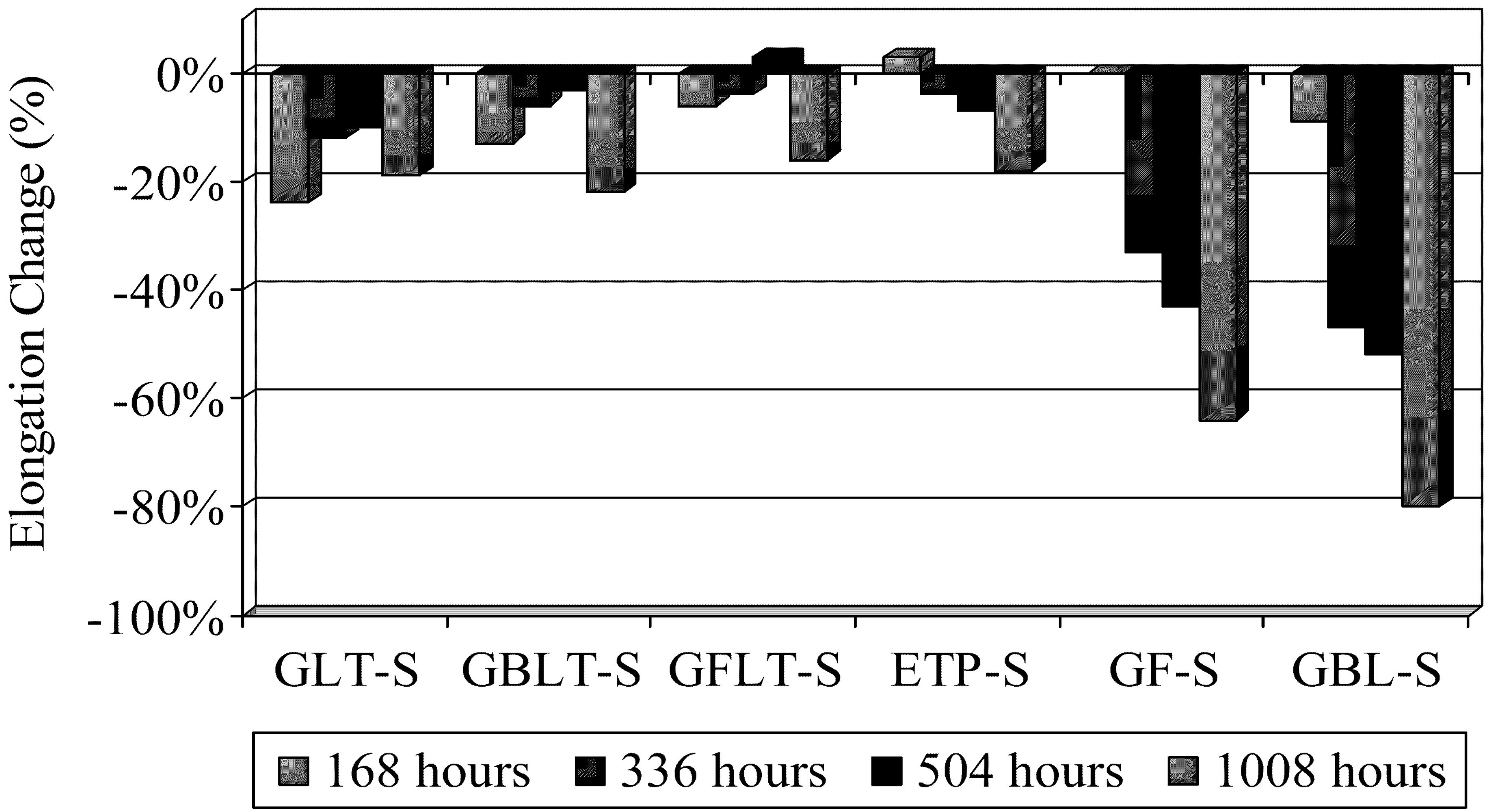
Testing Protocol

- Test Duration - 168, 336, 504 and 1008 hours
- Test Temperature - 200°C and 232°C
  - Testing Performed (oil changed weekly)
  - Original Physical Properties
  - Hardness Changes
  - Tensile Strength and Elongation Changes
  - Volume Swell
  - Compression Set
  - Compressive Stress Relaxation - out to 2016 hours
  - Low Temperature Properties

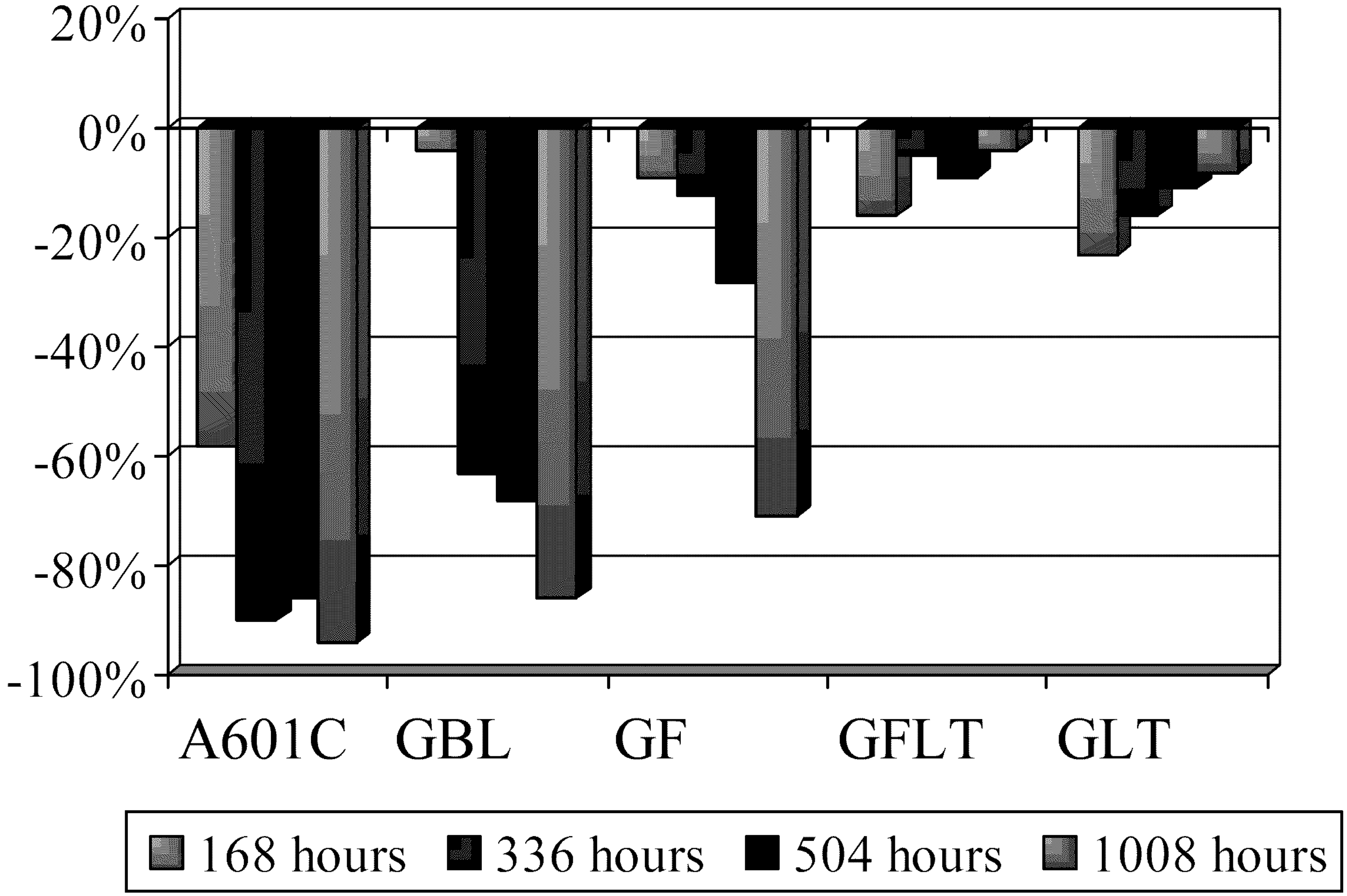
Elongation Change in Ref. Oil 300 at 200°C



Elongation Change in Reference Oil 300 at 200°C

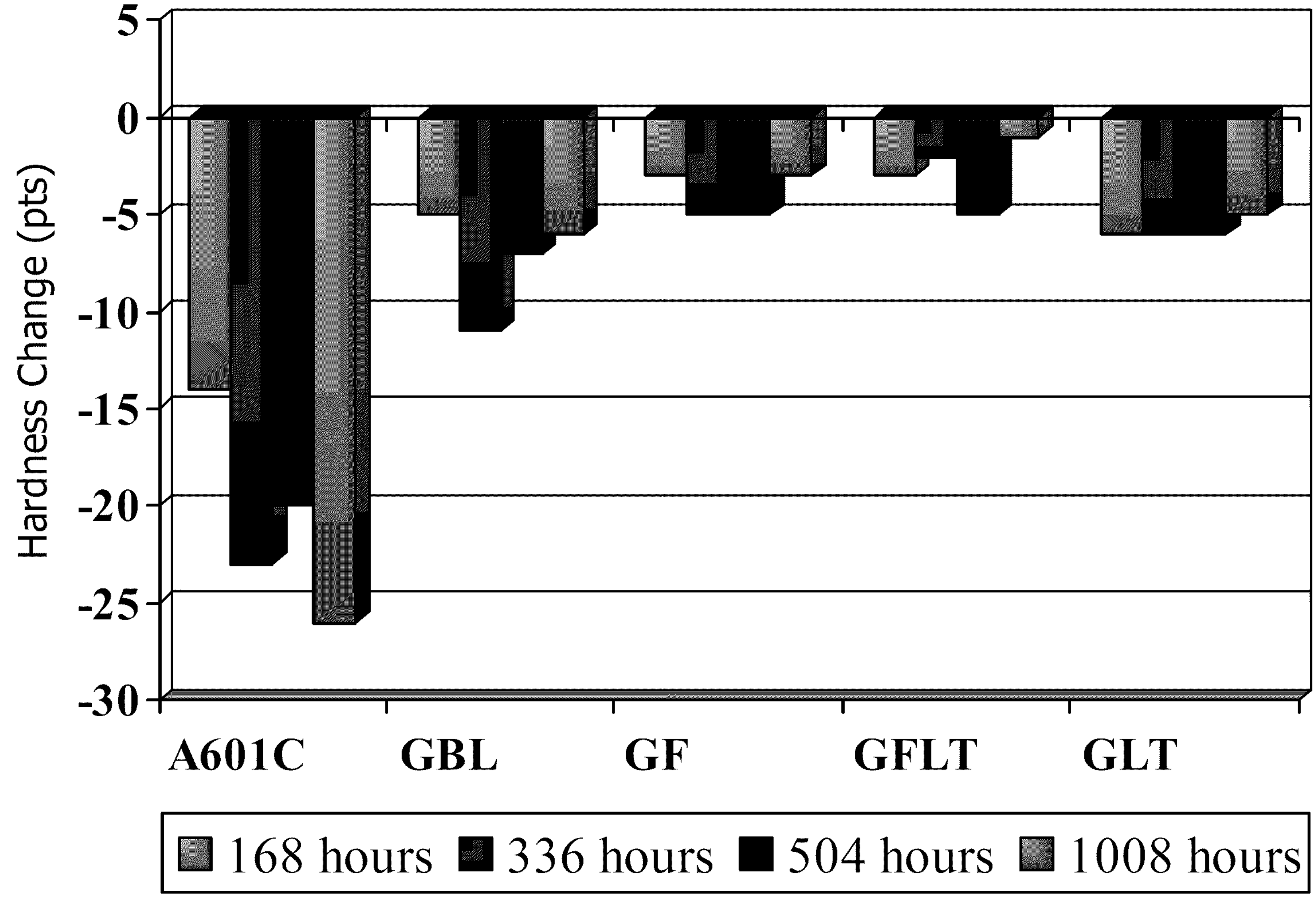


Tensile Strength Change in Ref. Oil 300 at 200°C

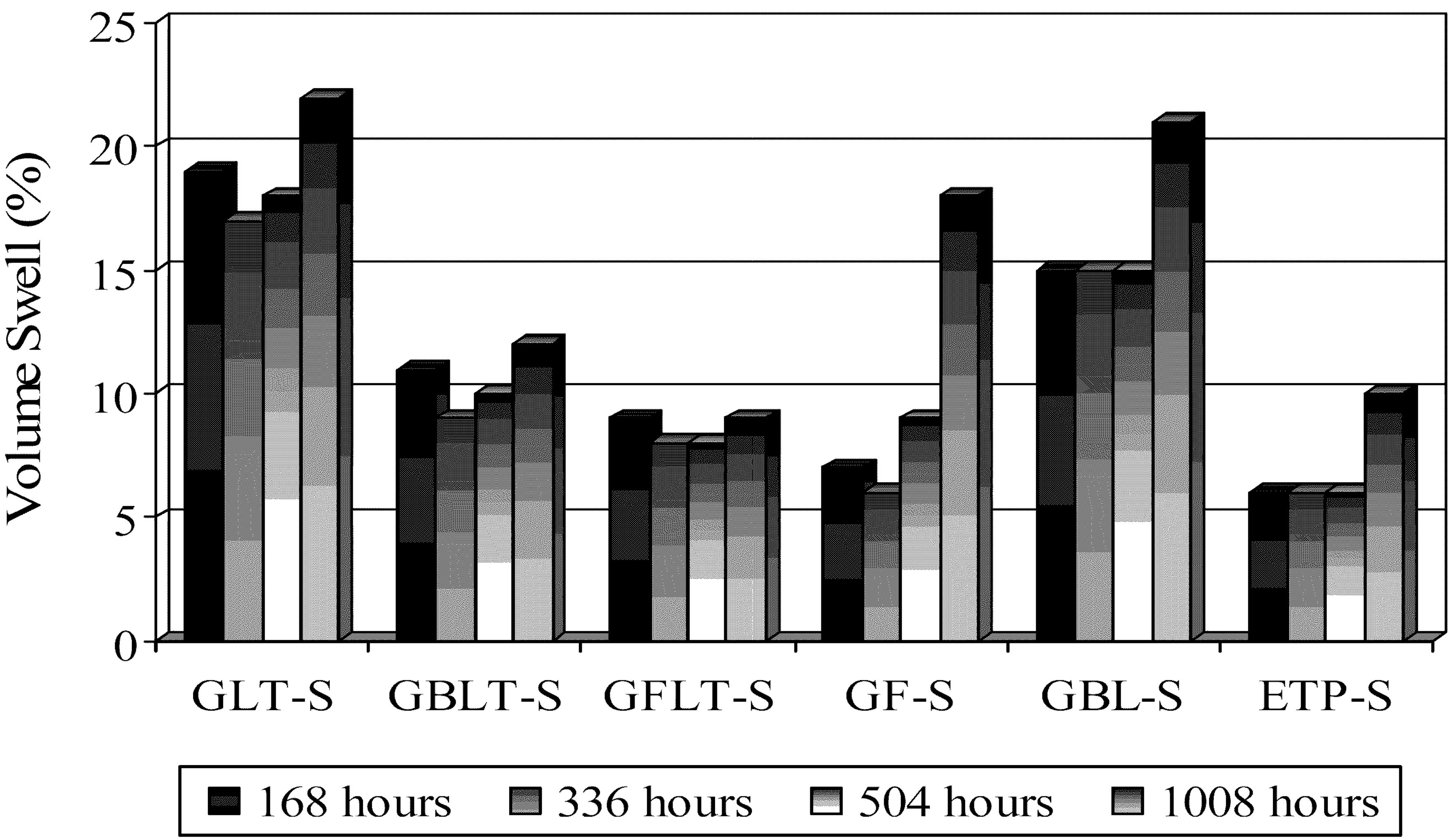


13

Hardness Change in Ref. Oil 300 at 200°C

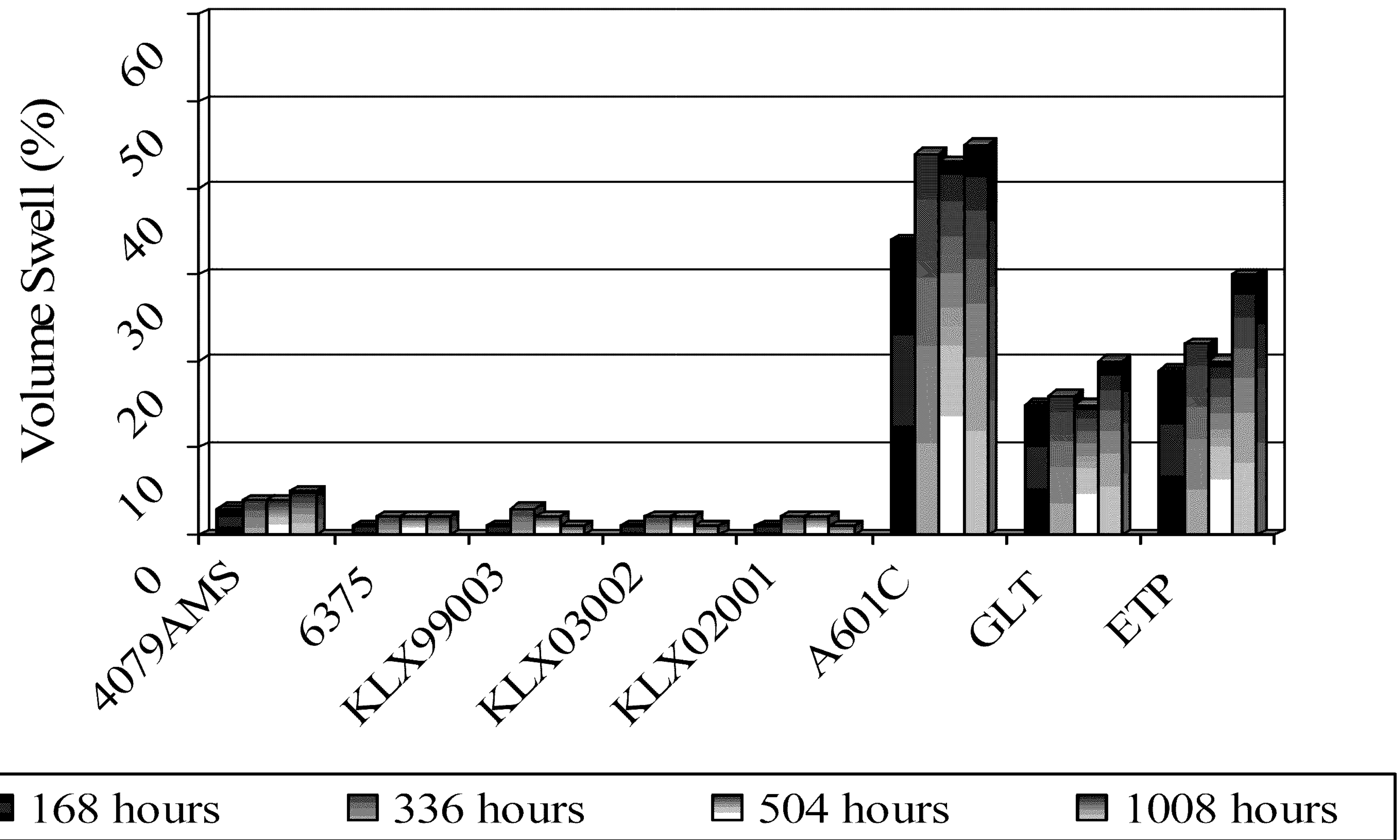


Volume Swell in HTS
Air BP 2197 at 200° C

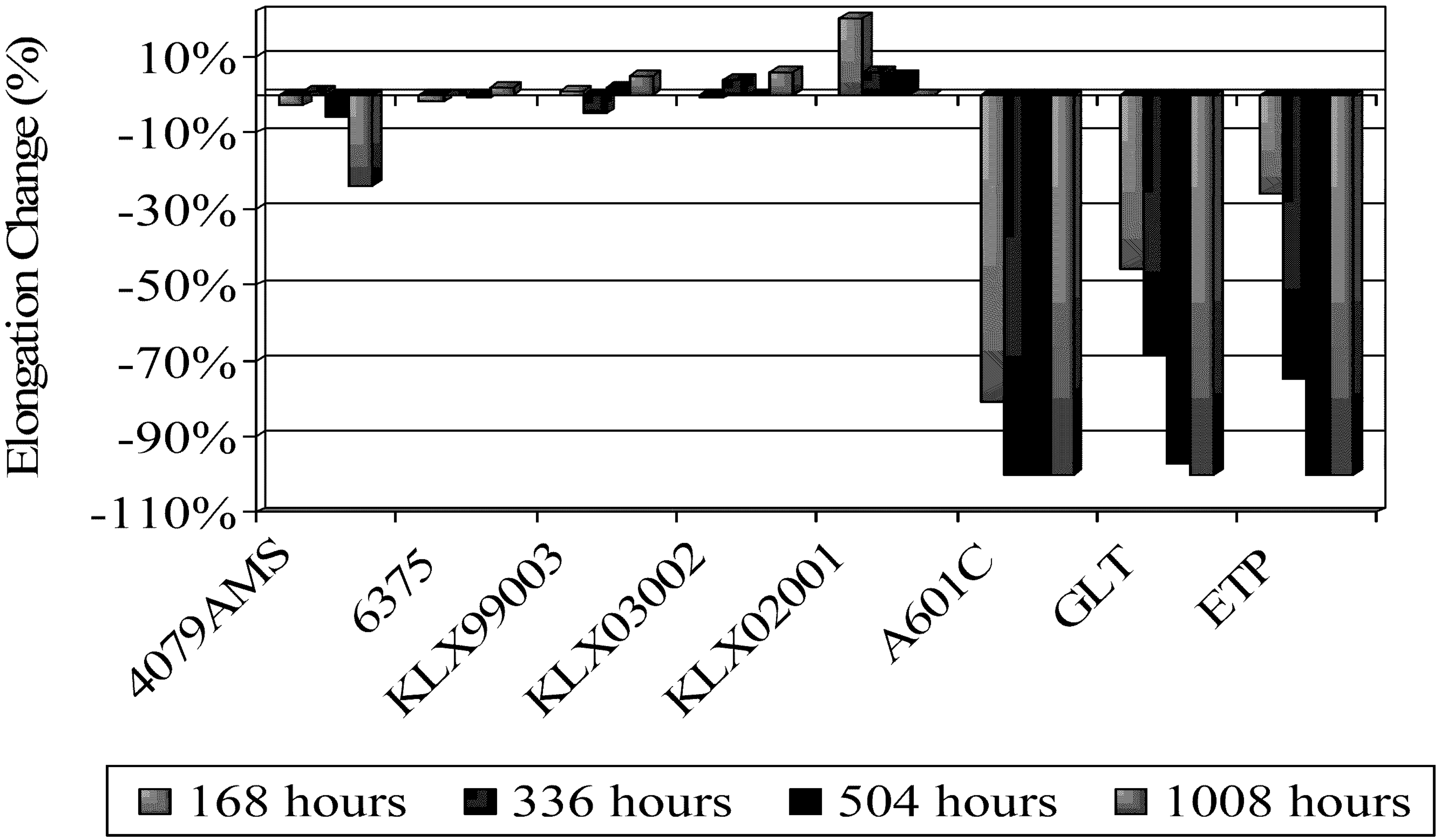


15

Volume Swell in HTS
MJO 291 at **232°C**

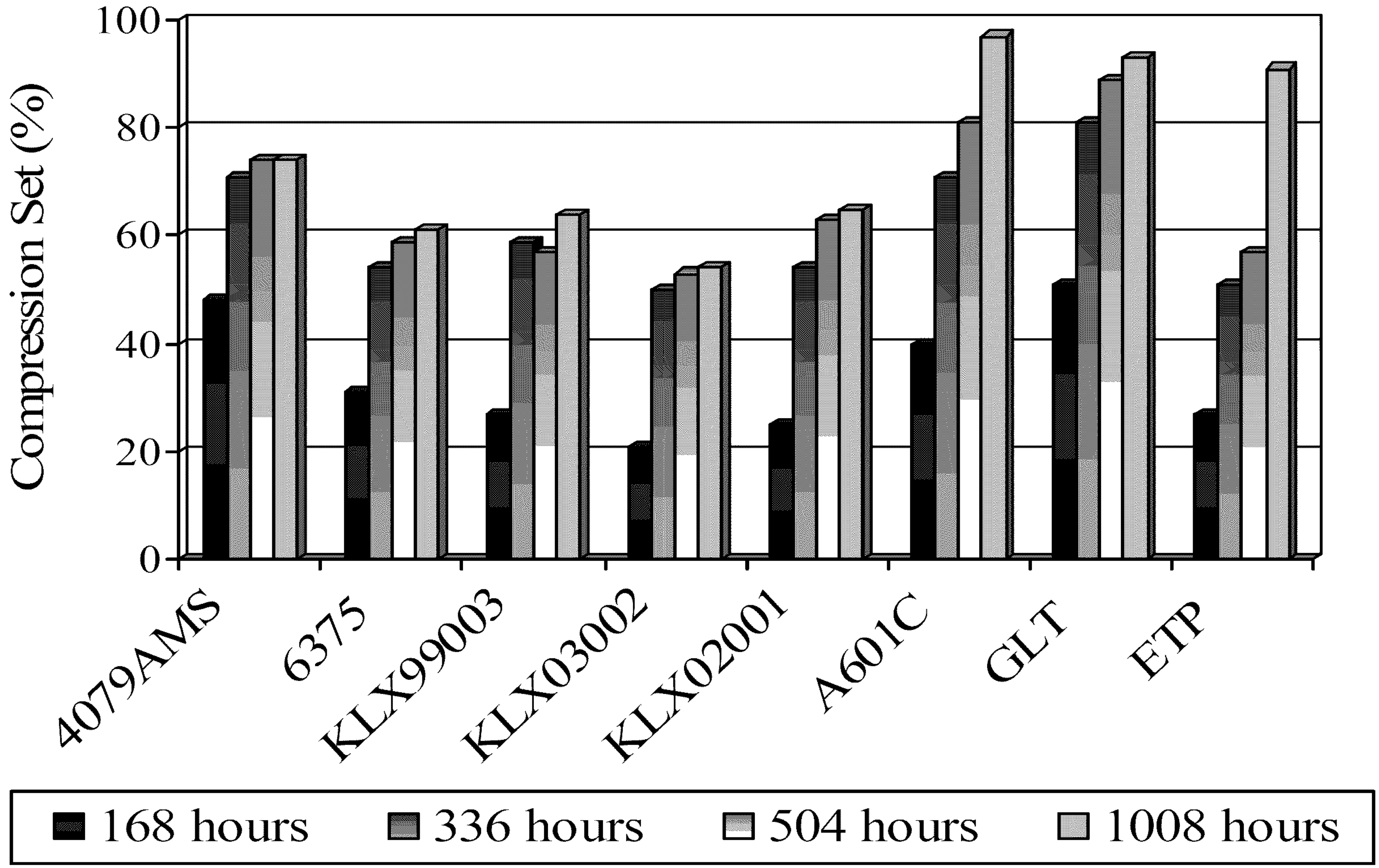


Elongation Change in HTS
BPTO 2197 at **232°C**



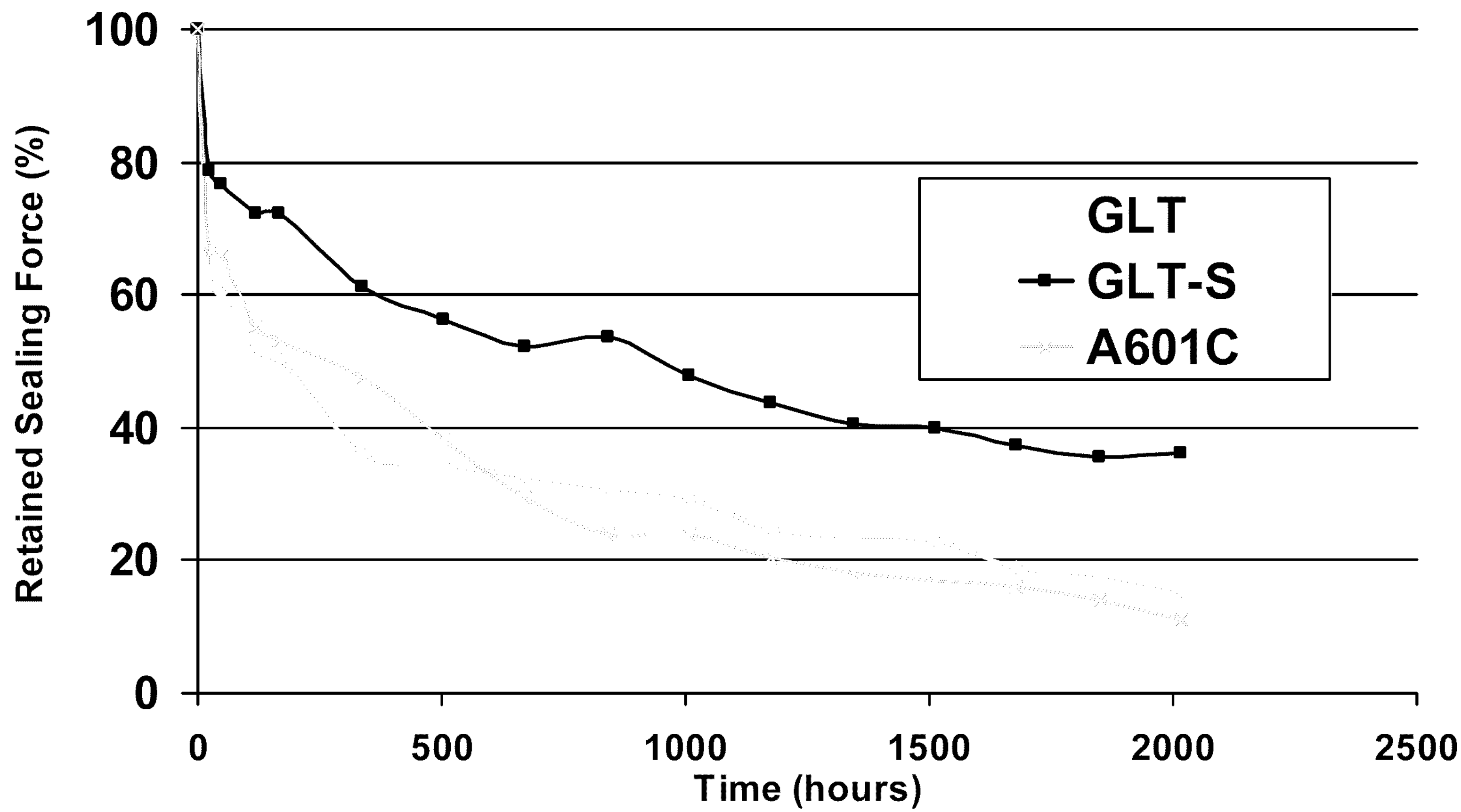
17

Compression Set in HTS
BPTO 2197 at **232° C**



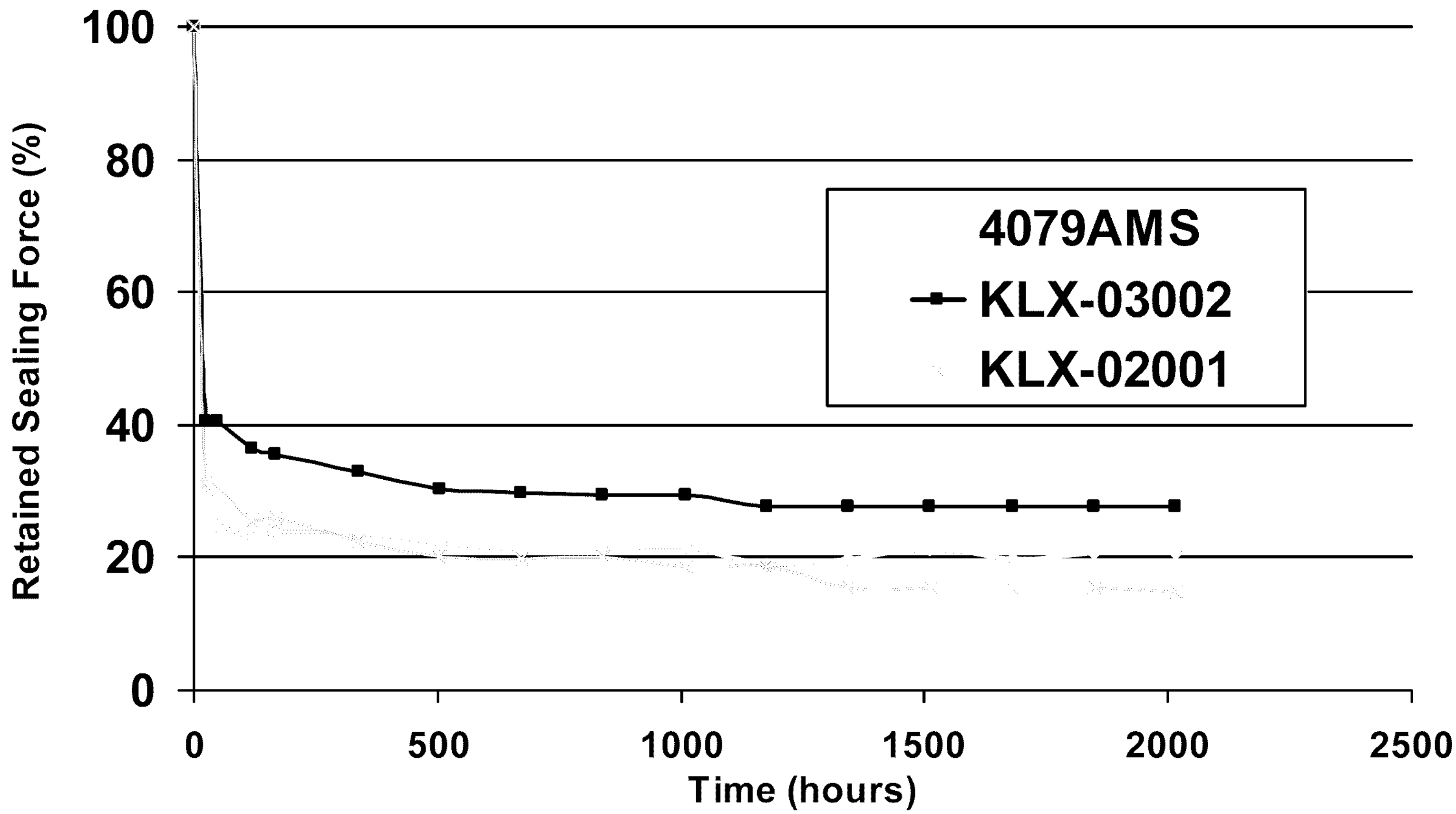
18

Stress Relaxation in Mobil Jet Oil 291 at 200°C

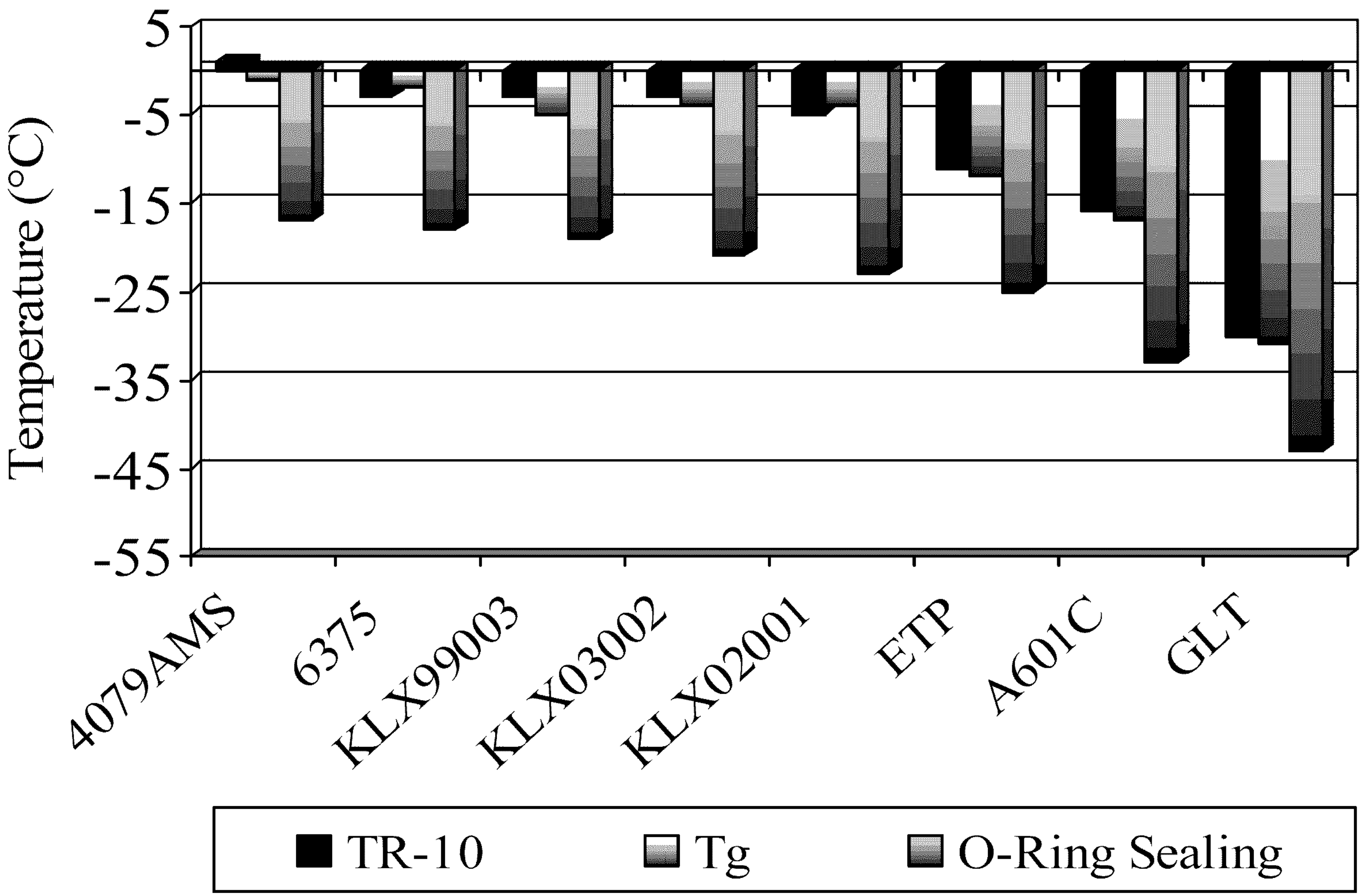


19

Stress Relaxation in Mobil Jet Oil 291 at 200°C



Low Temperature Properties



Summary
Fluoroelastomers

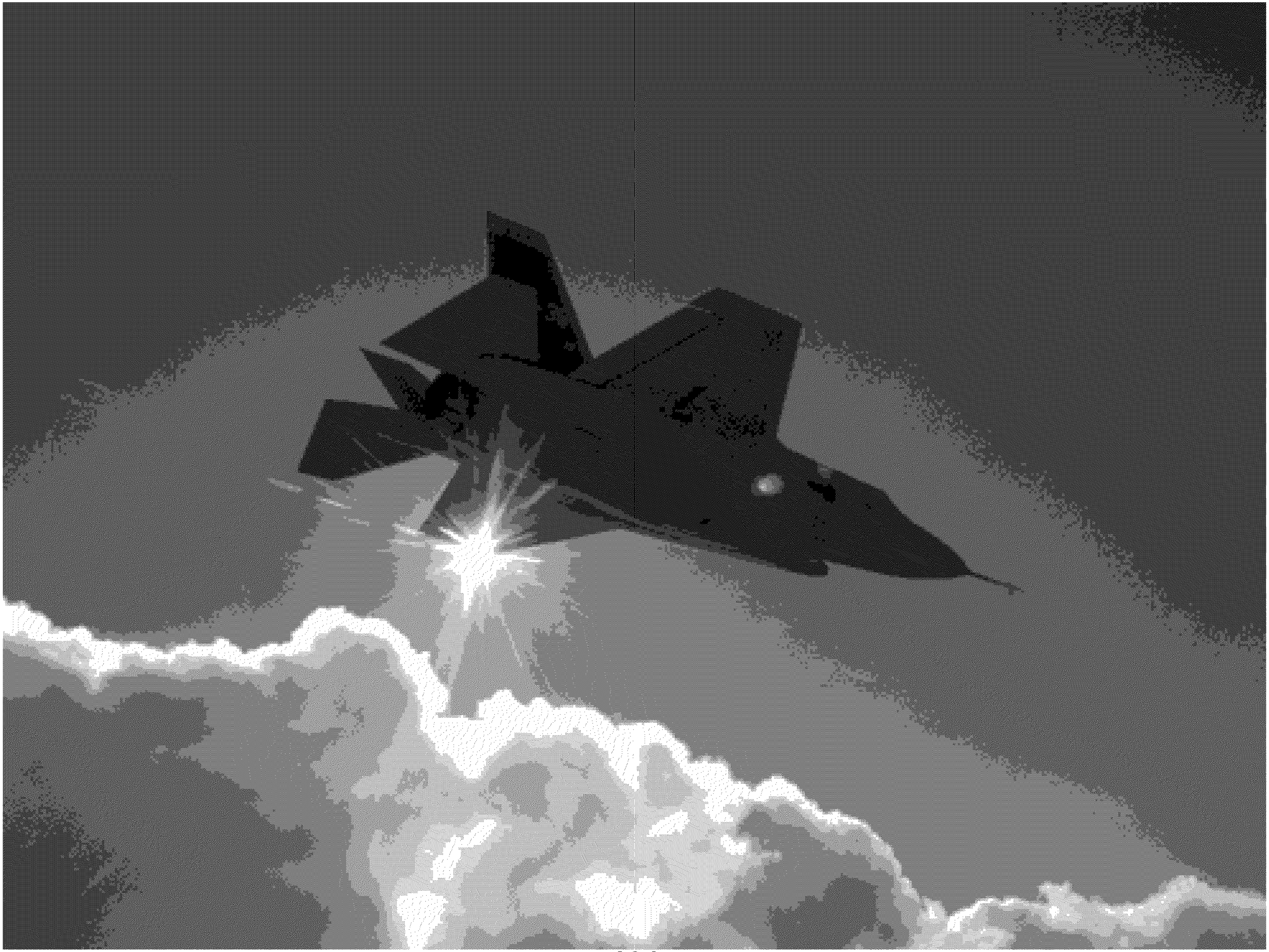
- A-type dipolymers fail via embrittlement
- Exhibit thermal capabilities up to 200°C
- GFLT-S & ETP-S provide the lowest swell in reference oils and jet lubes
- GLT-S, GBLT-S, GFLT-S and ETP-S show good retained stress/strain properties in jet lubes
- GLT-S has the best retained sealing force in jet oils up to 200°C as measured by CSR
- GLT-S provides the best low temperature properties within the elastomers evaluated

Summary
Perfluoroelastomers

- All the perfluoroelastomers evaluated are inherently "base resistant"
- They exhibit little to no degradation by either standard or HTS-type lube oils up to and beyond the thermal limits of the oil
- FFKM-4079AMS meets AMS 7257C and has become an industry standard for perfluoroelastomer sealing service
- We are actively evaluating better candidates to meet industry needs

Development of New Materials

- DuPont's Testing Shows a Need for Higher Temperature Materials
- Only a Few Very Expensive Materials Can Go Beyond 200°C
- Some Newly Developed, but Untested Materials Exist
- New Materials May Need to be Developed
- Materials would be Tested
- New Material Specifications would be Written



461

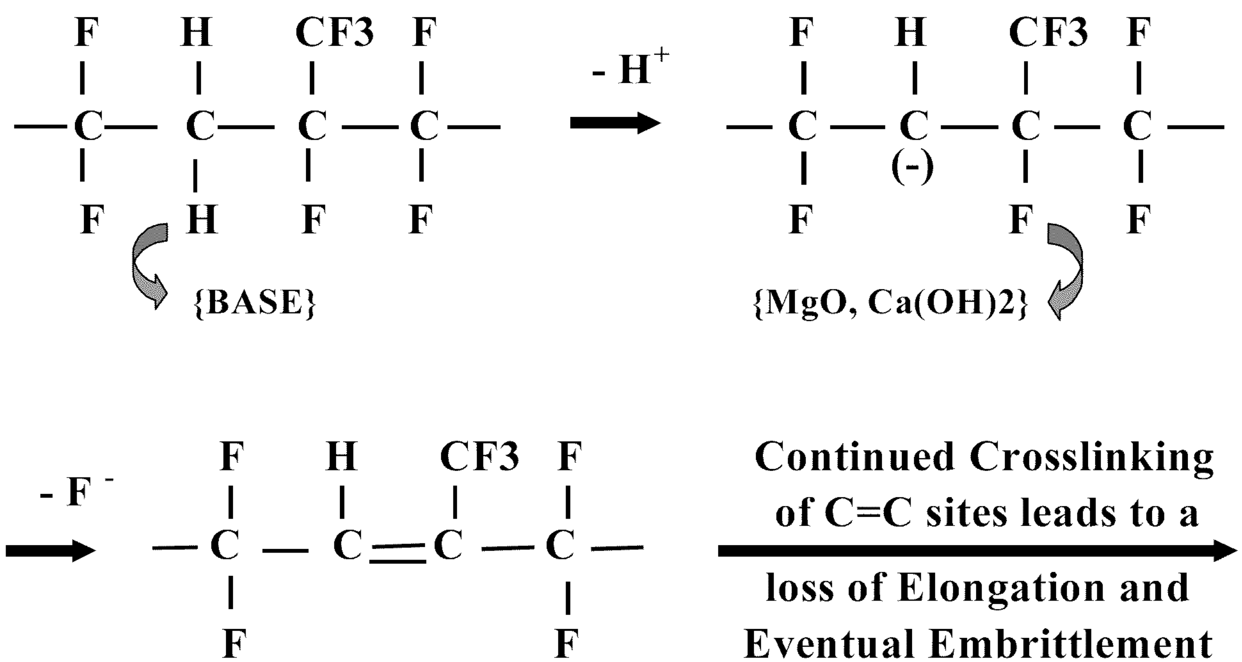
Backup

backup

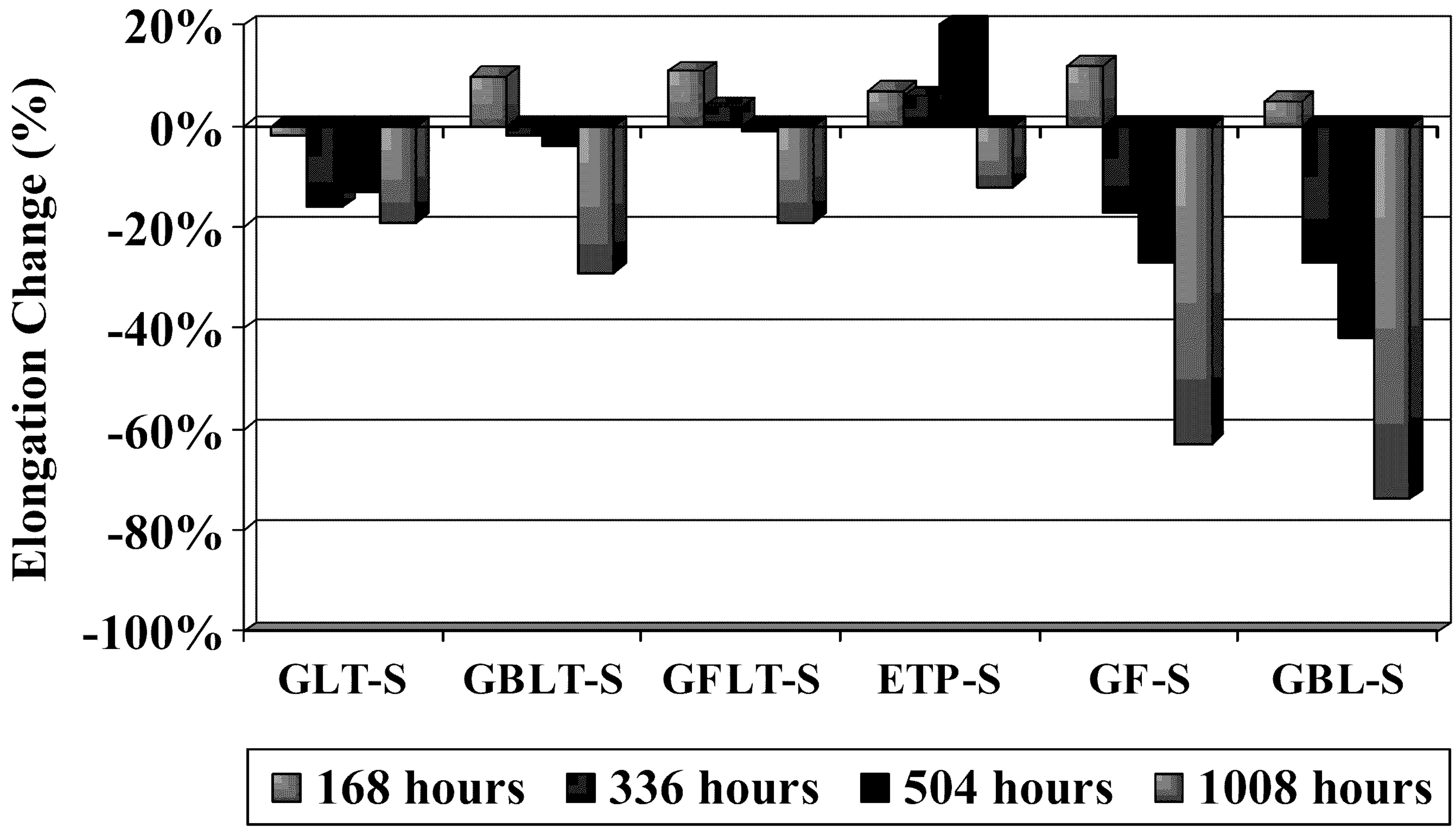
A proposed mechanism of chemical attack on standard fluoroelastomers

Base Attack on VF_2 / HFP FKM

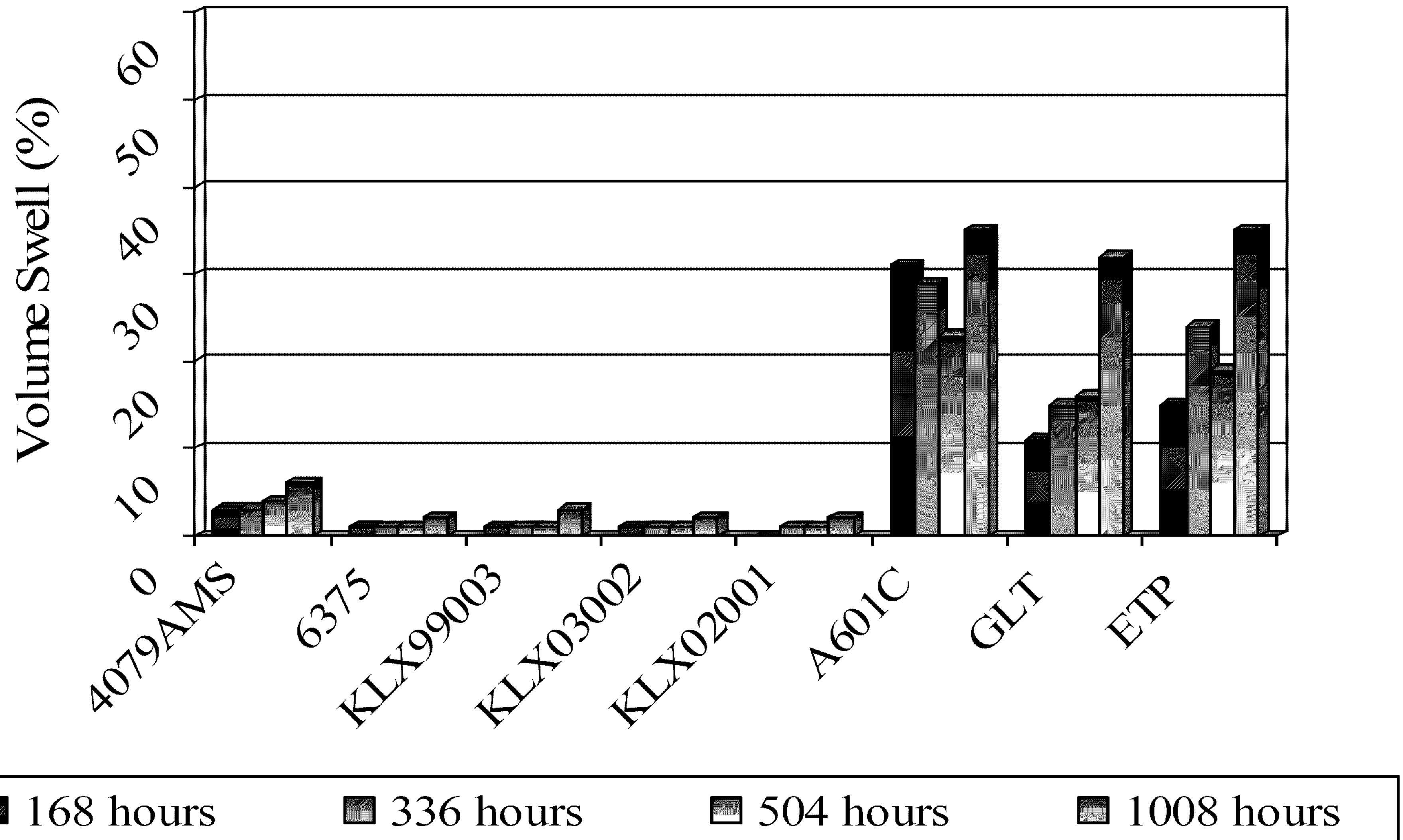
(VF_2 /HFP Sequences are the weak link in FKM)



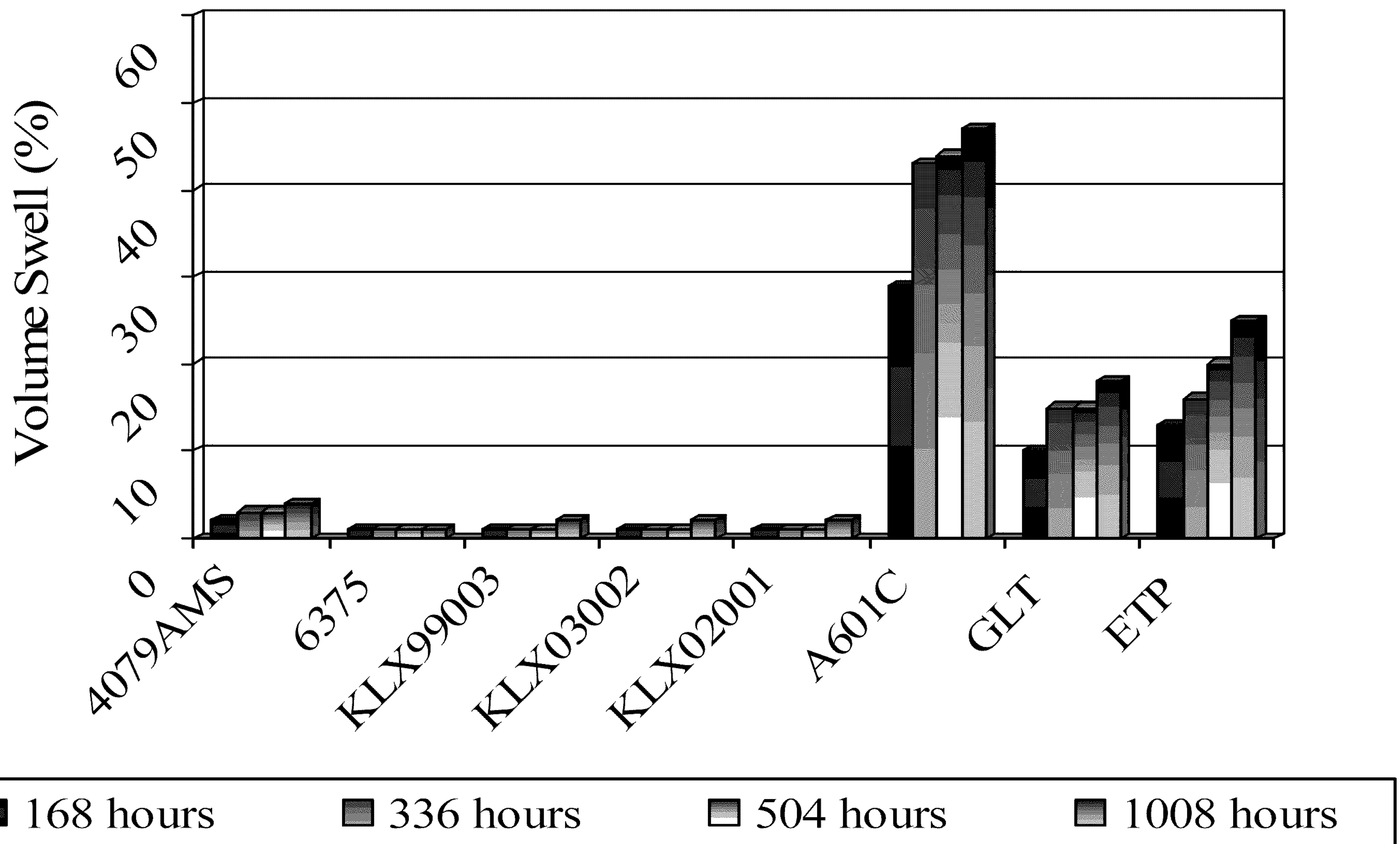
Elongation Change in Air BP 2197 at 200°C



Volume Swell in BPTO
2380 at **232°C**

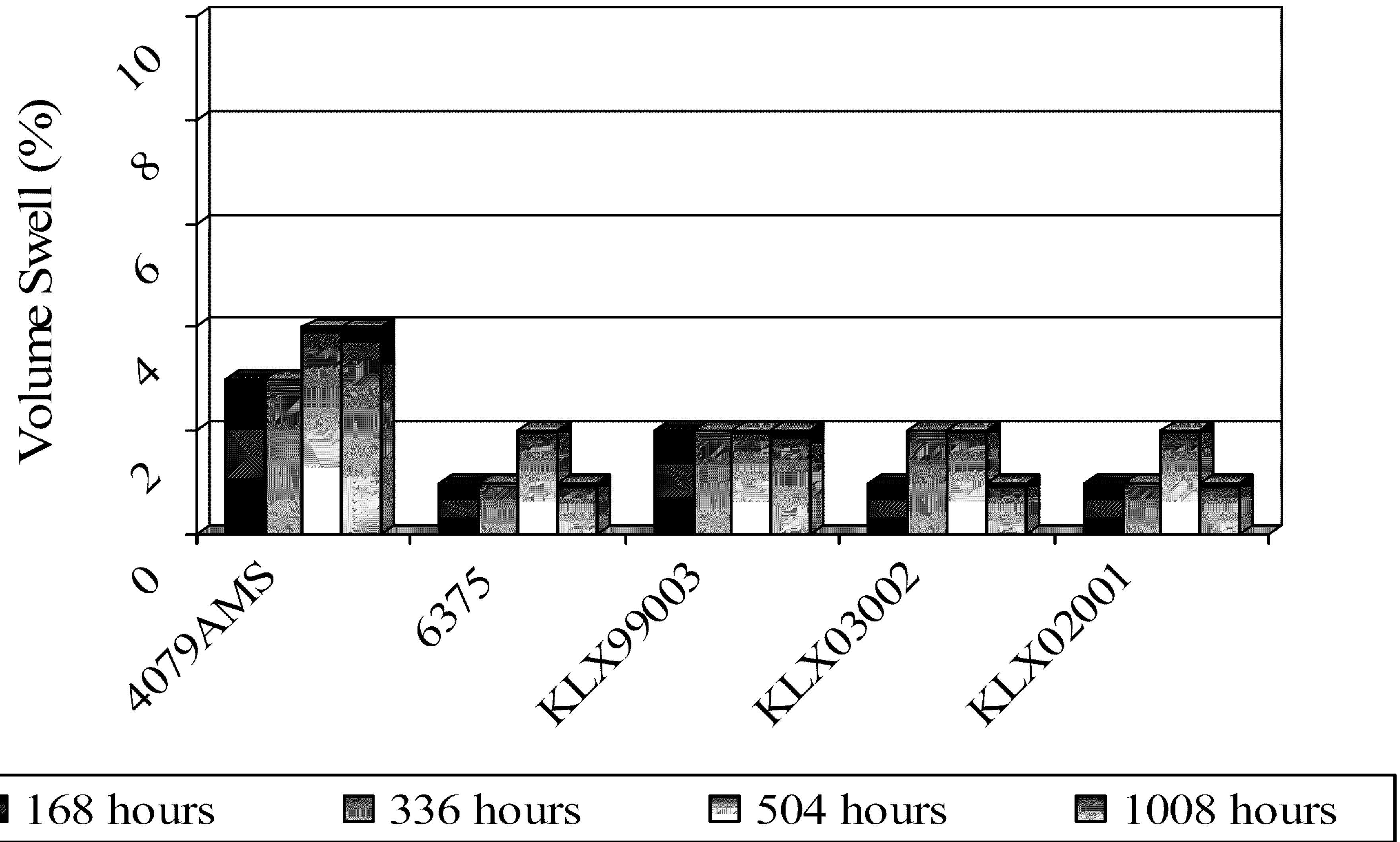


Volume Swell in ATO 560 at **232°C**



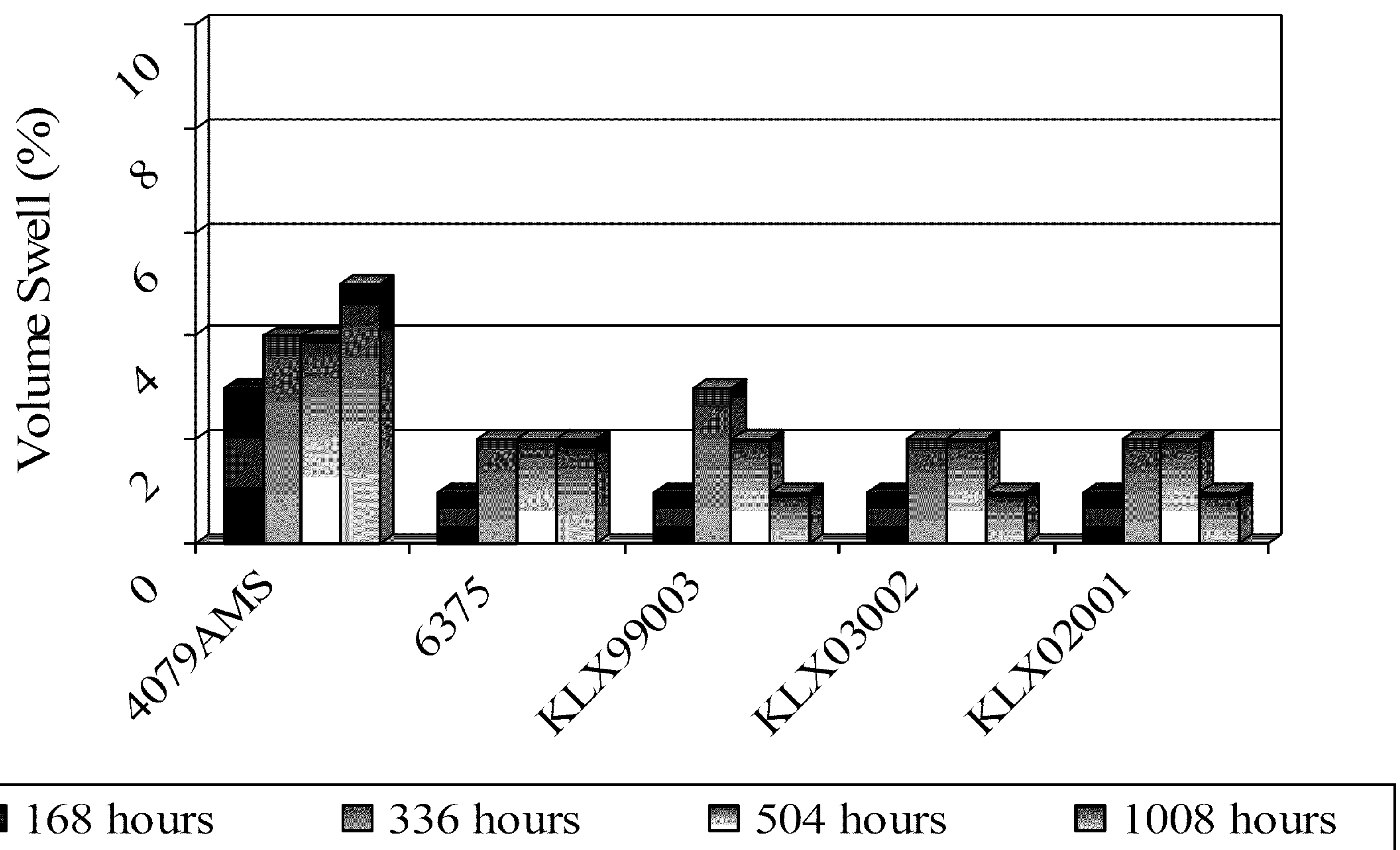
30

Volume Swell in HTS
MJO 254 at **232°C**



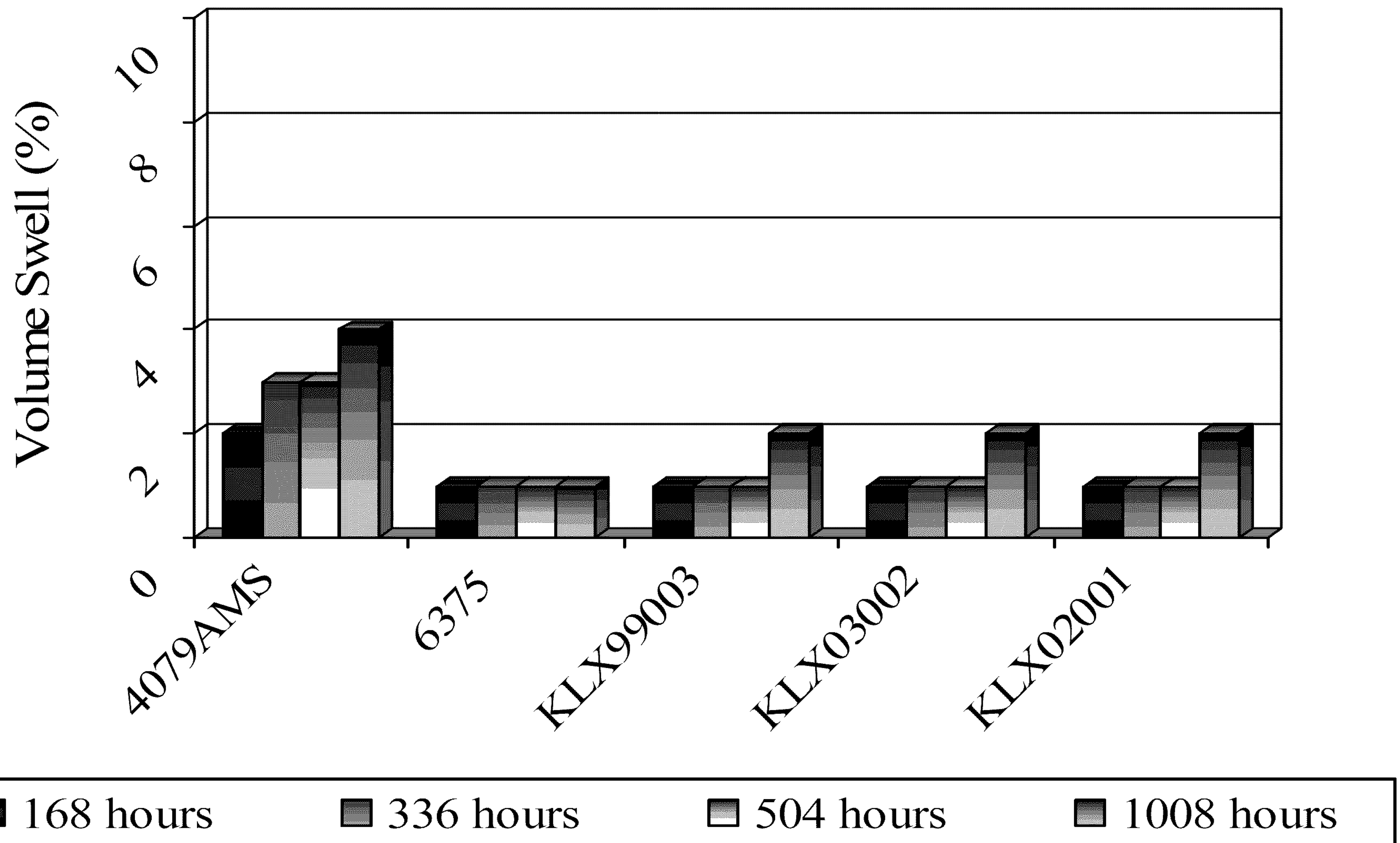
31

Volume Swell in HTS
MJO 291 at **232°C**



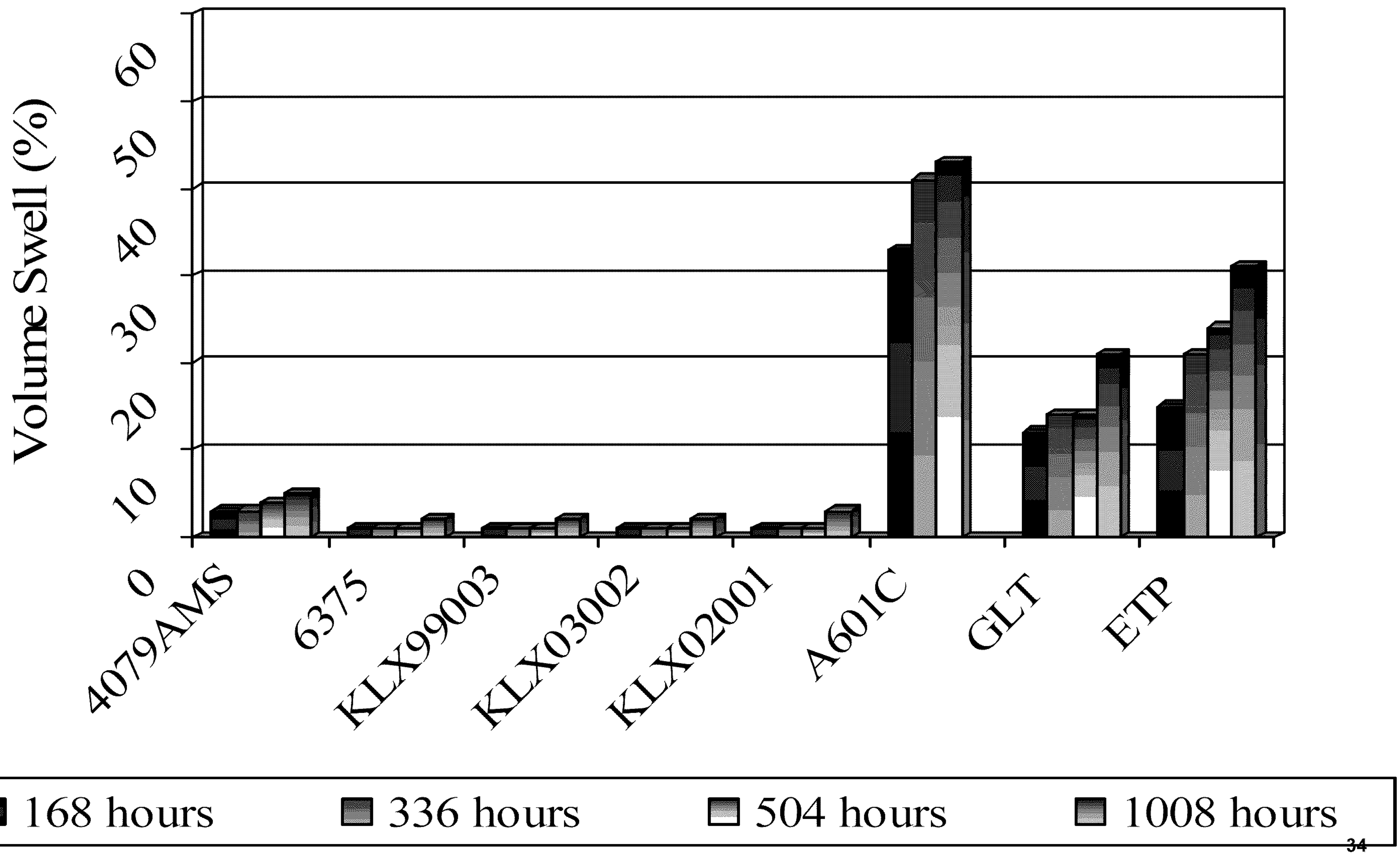
32

Volume Swell in HTS
ATO 560 at **232°C**

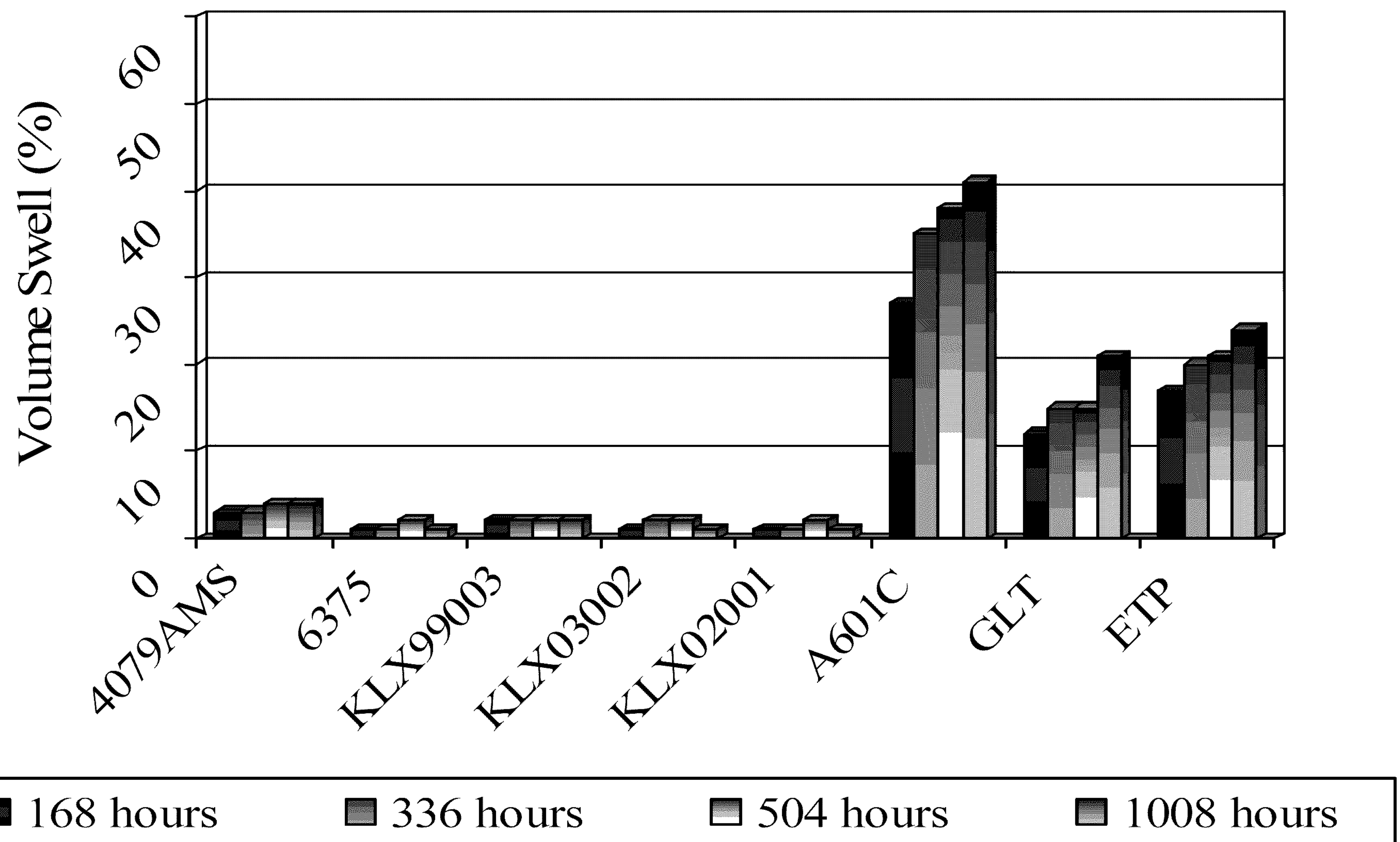


33

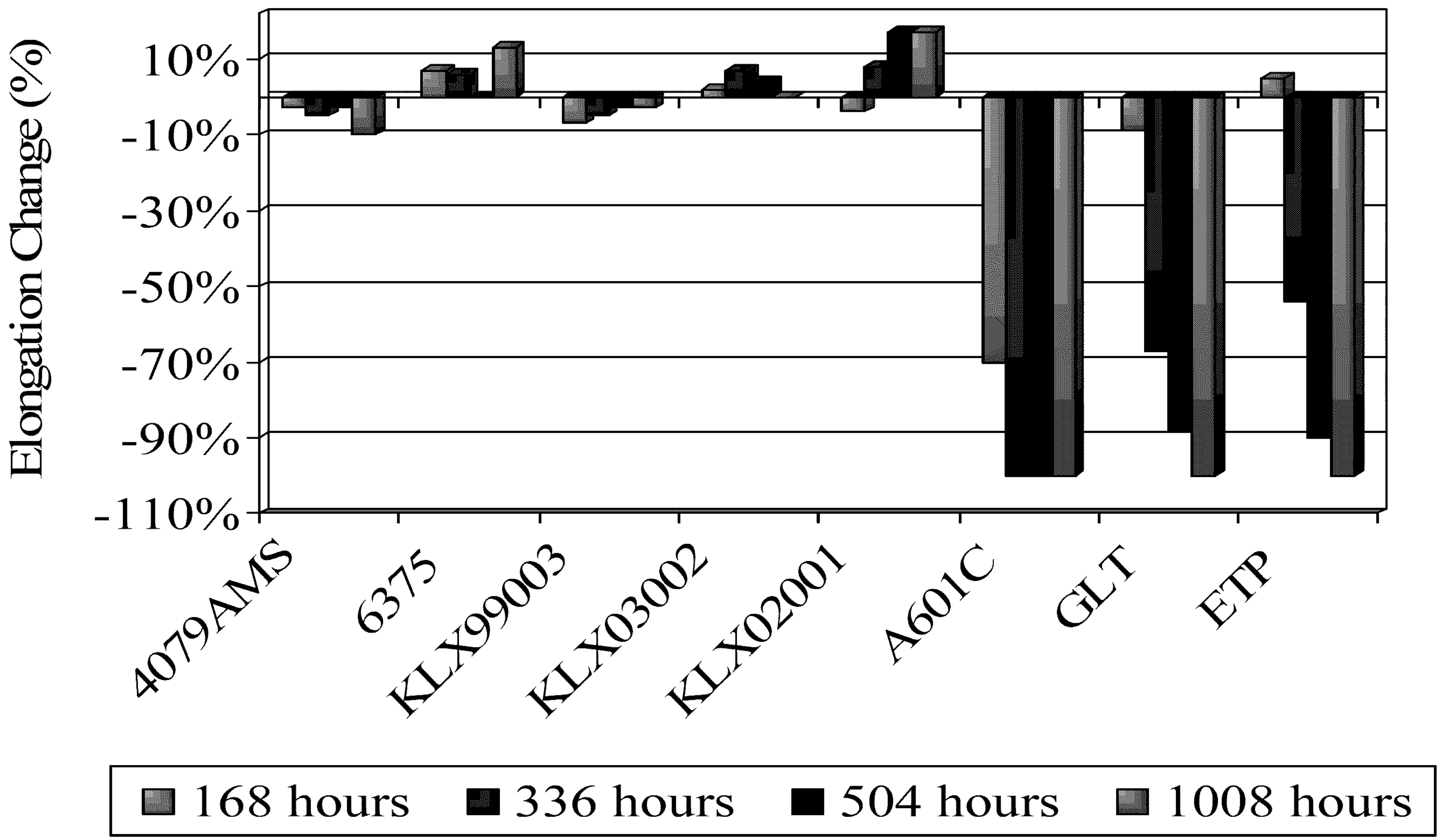
Volume Swell in MJO II at **232°C**



Volume Swell in HTS MJO 254 at **232°C**

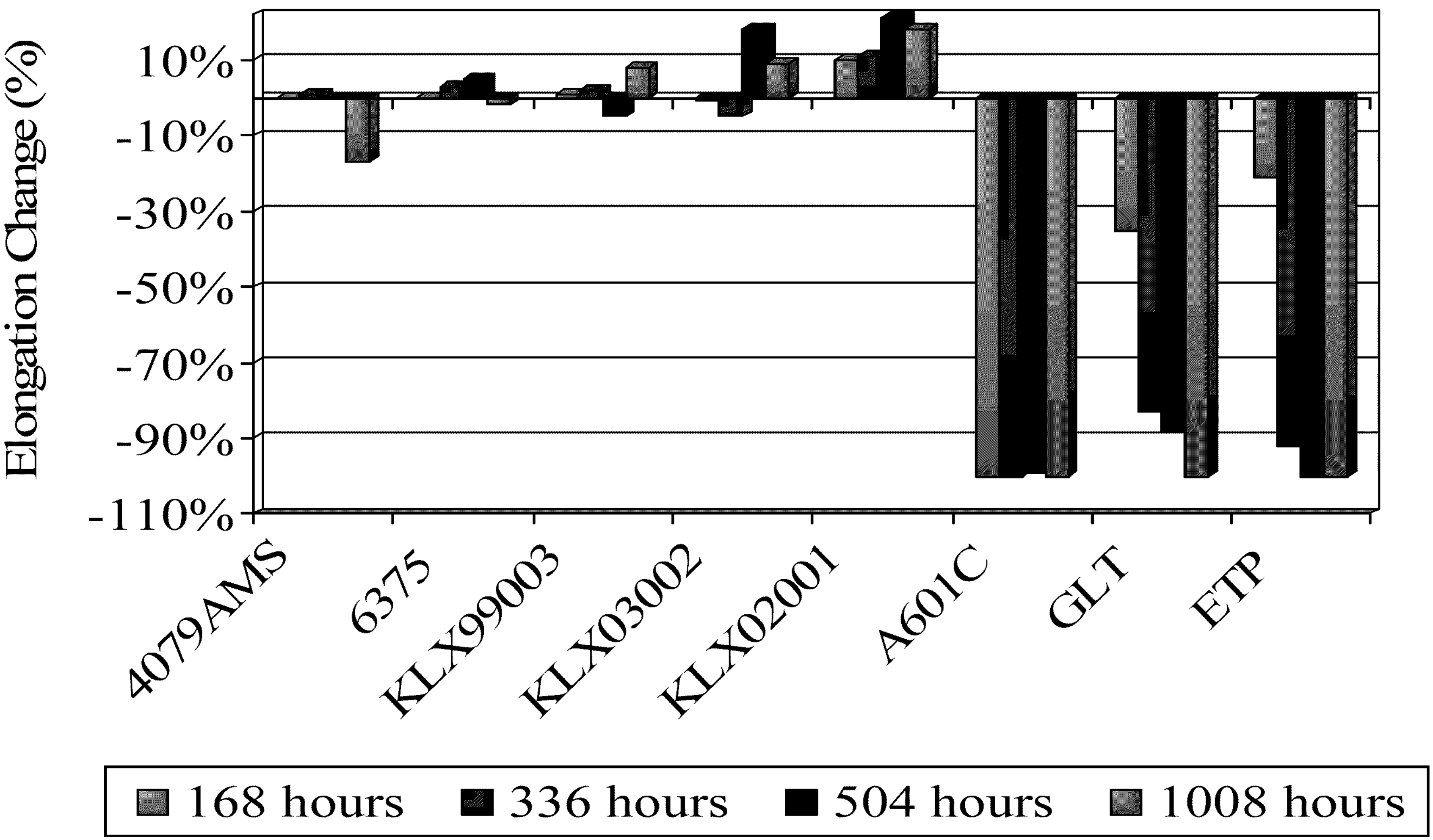


Elongation Change in ATO 560 at **232°C**

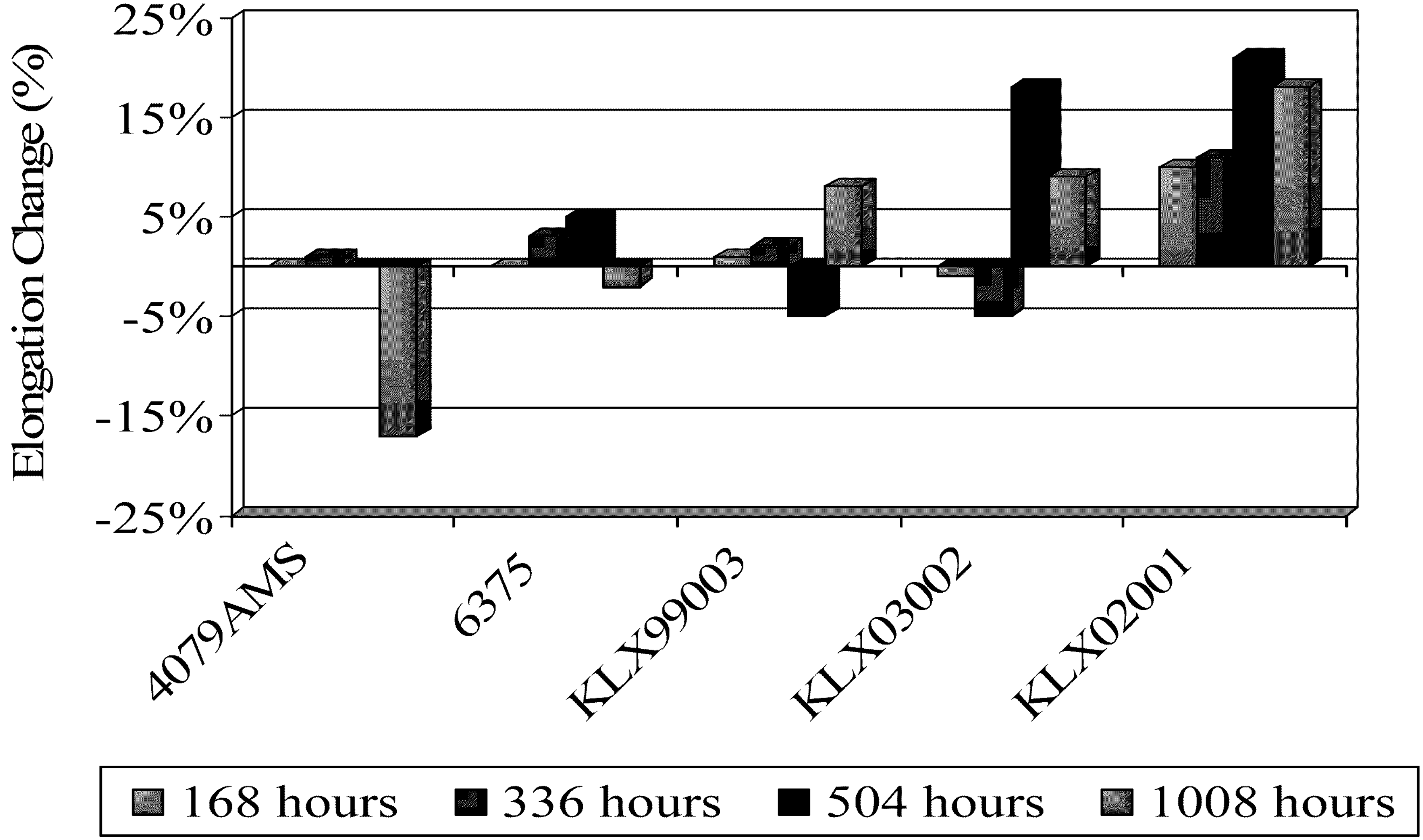


36

Elongation Change in BPTO 2380 at **232°C**

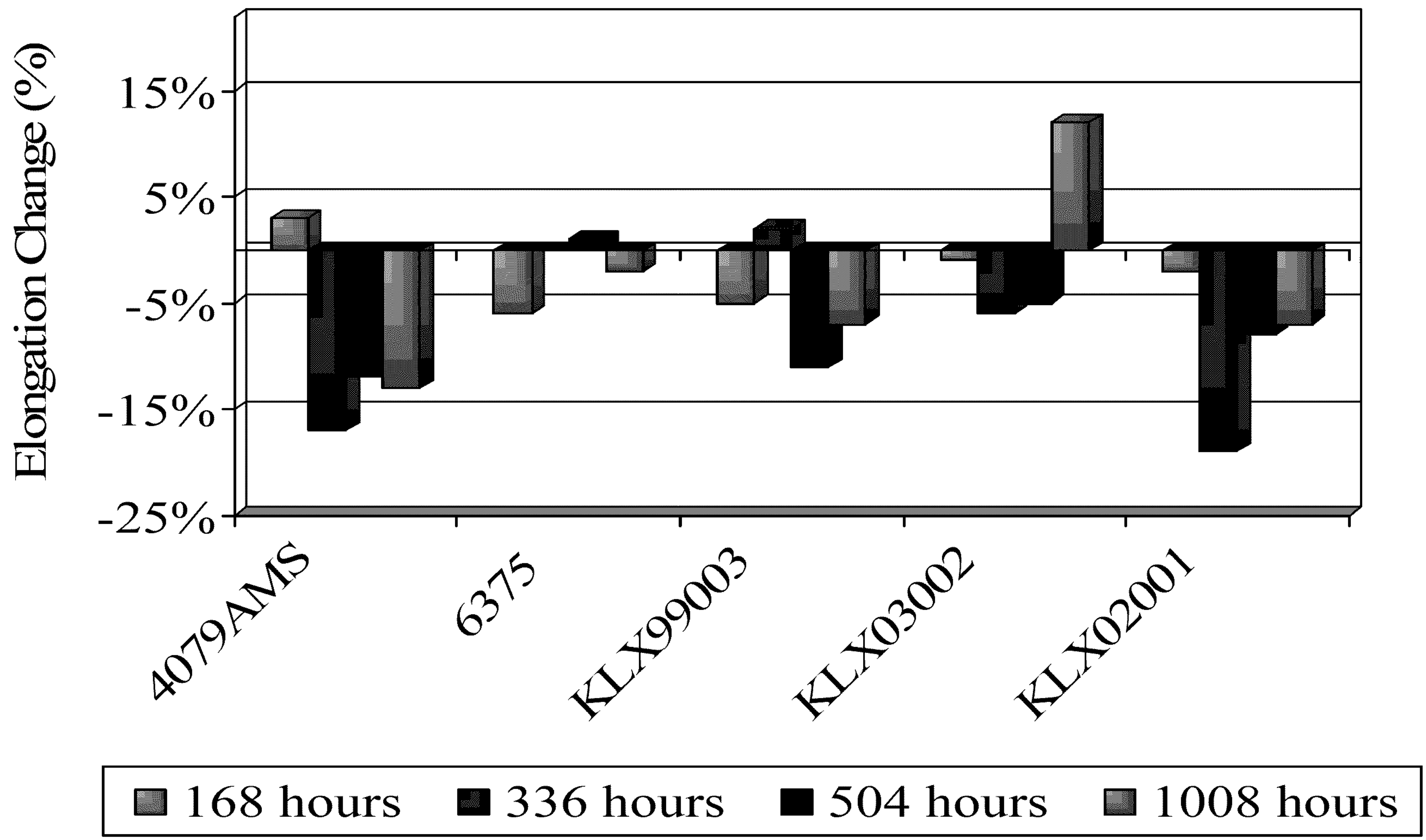


Elongation Change in BPTO 2380 at **232°C**



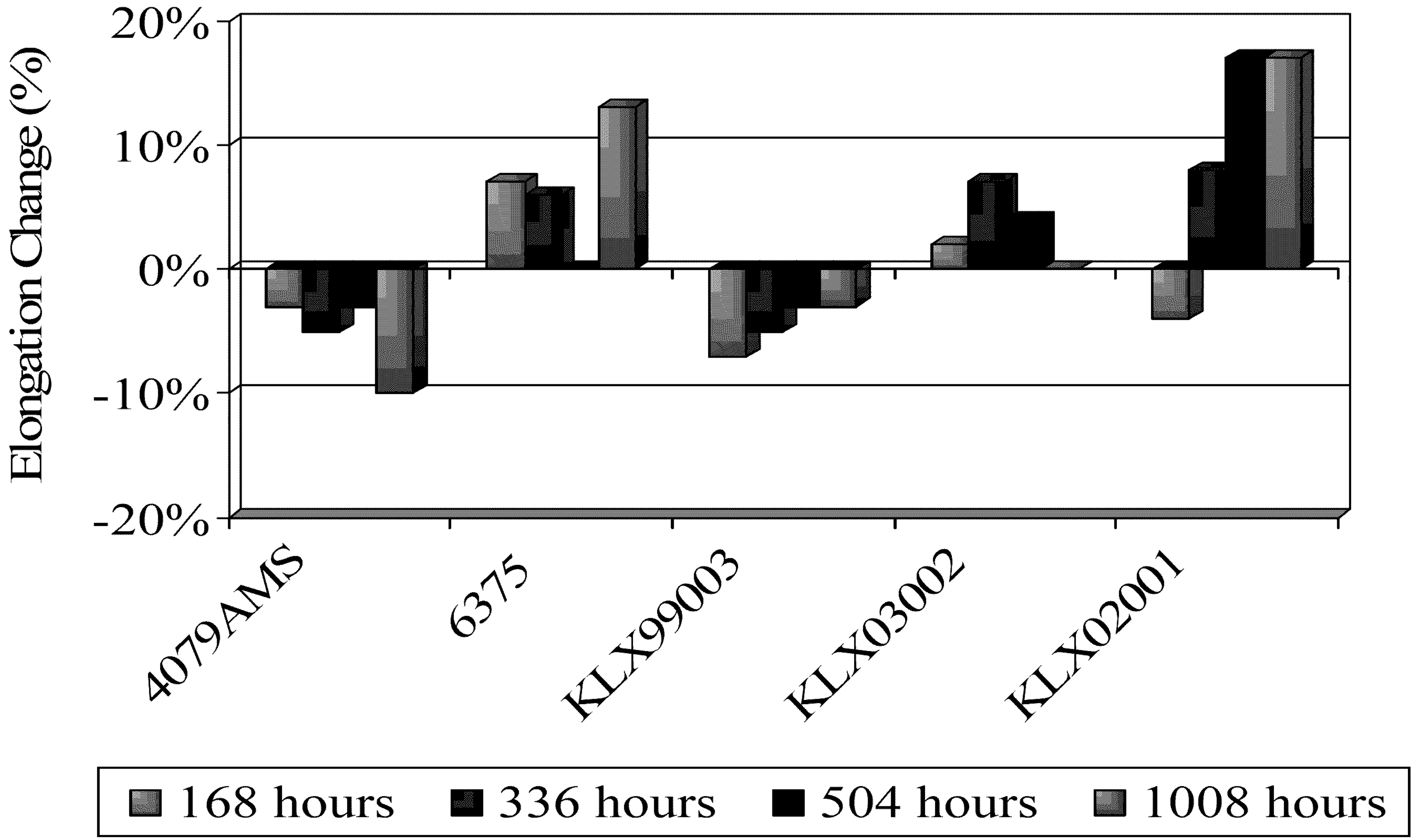
38

Elongation Change in MJO 254 at **232°C**



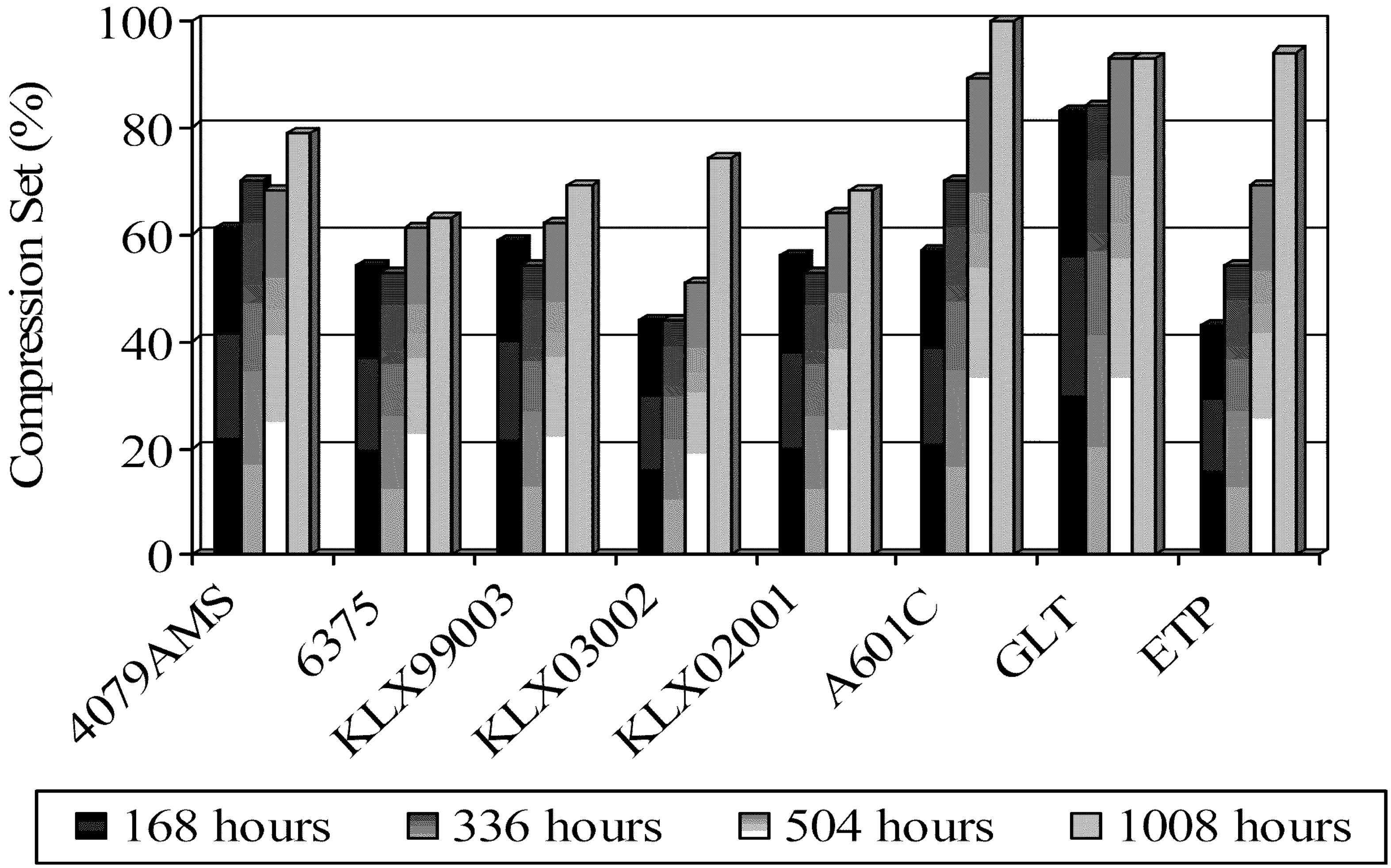
39

Elongation Change in ATO 560 at **232°C**



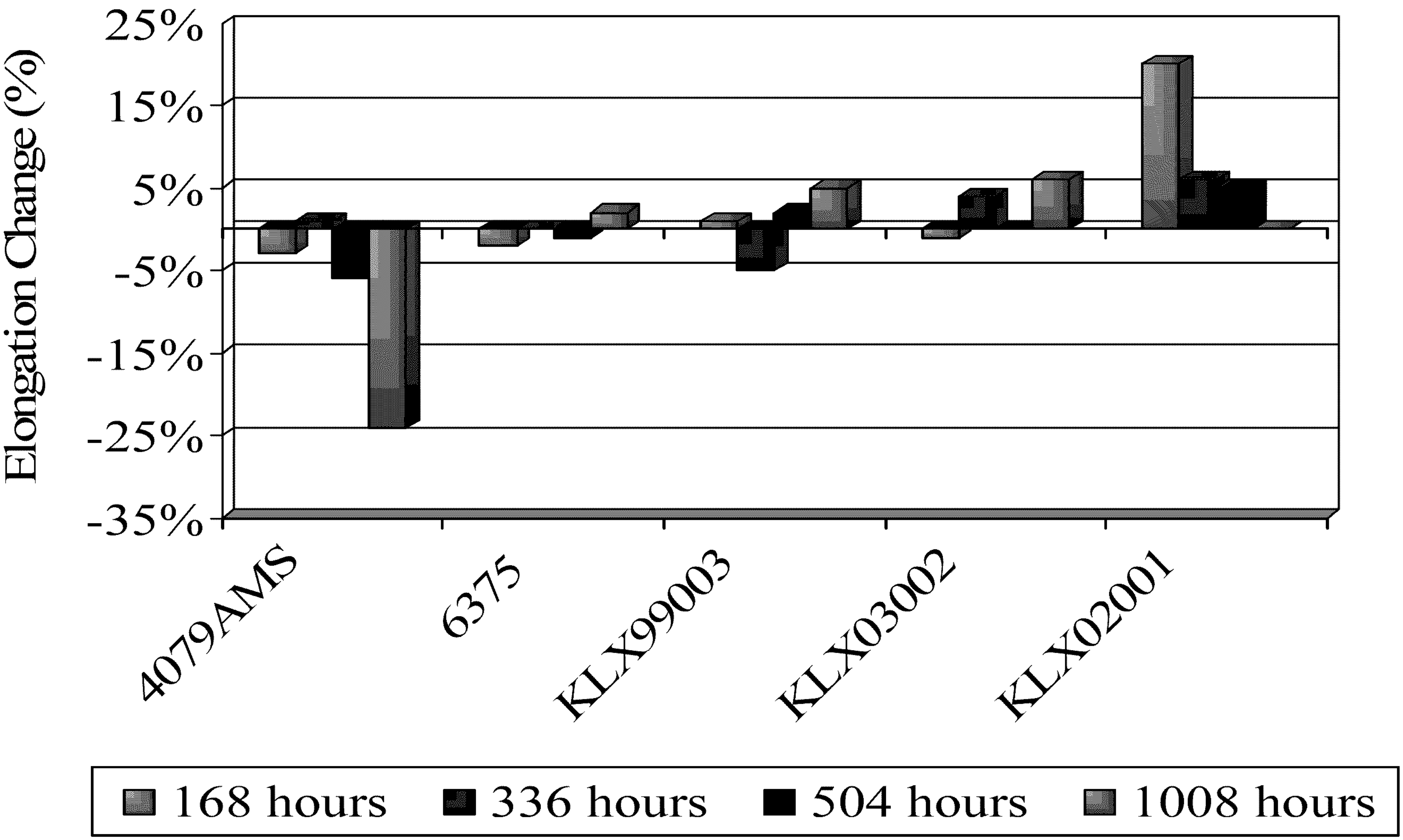
40

Compression Set in MJO 291 at **232° C**



41

Elongation Change in HTS
BPTO 2197 at **232°C**



42

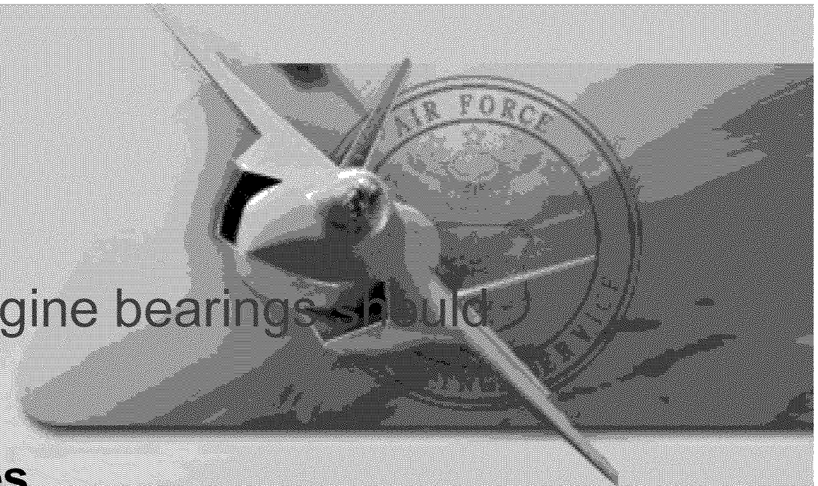
Gas Turbine Engine Oil Antiwear Additives for Advanced Bearing Steels

SBIR AF03-119
June 16, 2004

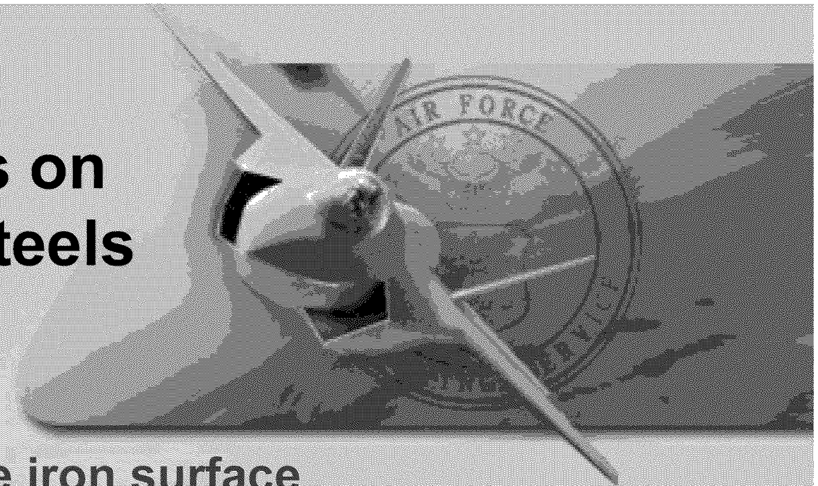
Richard Sapienza
Bill Ricks
Joe Sanders
Chris Kubala
METSS CORPORATION

Contract : F33615-03-M-5023
POC: L. Gschwender, AFRL/MLBT

The Problem



- Advanced high-chrome steels in engine bearings should provide:
  - ✓ **higher operating temperatures**
  - ✓ **higher speed capabilities**
  - ✓ **improved corrosion**
  - ✓ **fatigue resistance**
- However, they have experienced significantly shorter life than anticipated in performance tests conducted using current gas turbine engine oils (GTOs).
- Their chemistry does not interact in the same way with the lubricious coating additives.

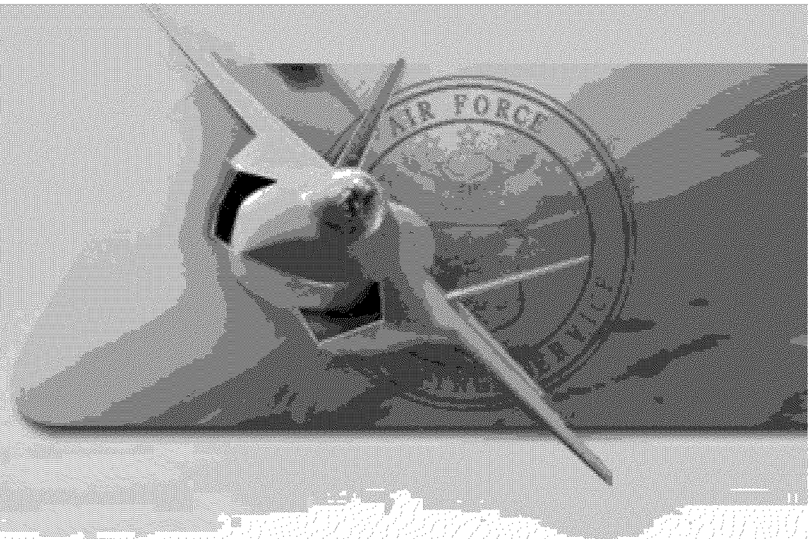


Reaction of Antiwear Additives on Conventional Low Chromium Steels

- antiwear additives react chemically with the iron surface
  - *a lubricious coating on steel surfaces under boundary lubrication*
- produce soft films of inorganic metallic chlorides, sulfides and phosphides.
  - *films shear easily where any asperities meet and thus protect the base metal.*

- It has been postulated that the high-chromium content of the advanced steels does not provide the proper reactive iron surface necessary for interaction with the aryl phosphate (TCP) to form an iron-phosphorus surface film

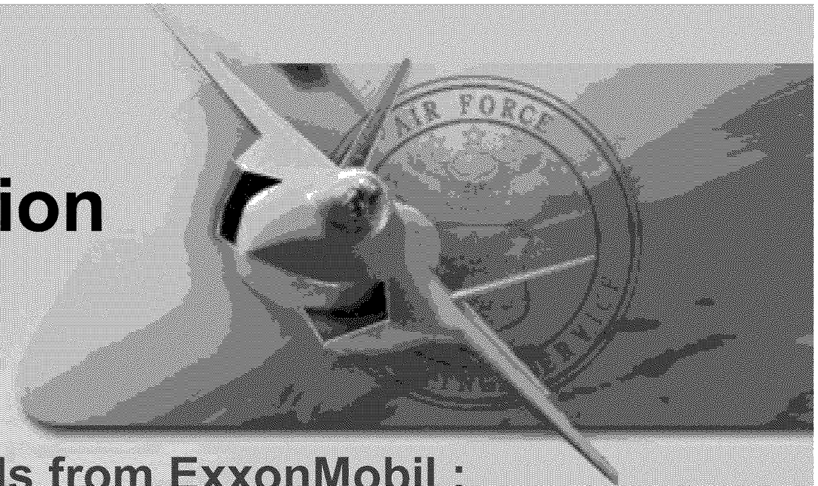
METSS Approach



- **Well defined technical program:**
  - *Identify needs, evaluate existing fluids*
  - *Select candidate alternative materials*
  - *Develop testing and evaluation program*
  - *Conduct iterative formulation, testing, and optimization*
    - **tiered approach to testing**
      - **simple screening tests to eliminate poor performers**
      - **more advanced tests to optimize formulations**
      - **final qualification tests to select best performers**
  - *Partner with Manufacturers - provide max feedback ; Work with AF- seek max information*

Goal - Identify several candidates that exhibit better antiwear properties than either the current TCP additive or the current finished fluid.

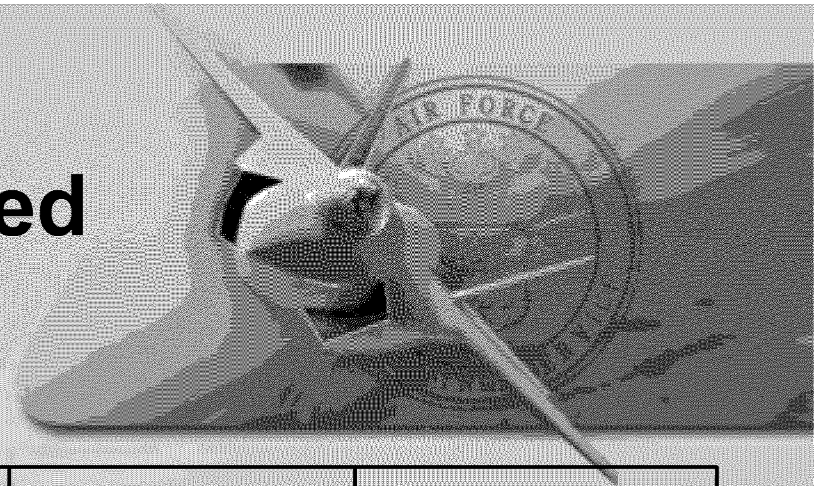
Lubricant Materials Selection



- METSS obtained samples of two base fluids from ExxonMobil :
  - *Fluid A. **ExxonMobil MCP 2433, a synthetic polyol ester basestock fluid containing no additives.***
    - **used as primarily the carrier for the candidate lubricant additives**
    - **one control was Fluid A with the current tricresyl phosphate antiwear additive.**
  - *Fluid B. **ExxonMobil RM284A, a MIL-PRF-7808 Grade 4 fluid, fully compounded with all additives, including the aryl phosphate.***
    - **Fluid B was used as one of the controls**
- **METSS found suppliers and other additive technology to prepare fluids.**

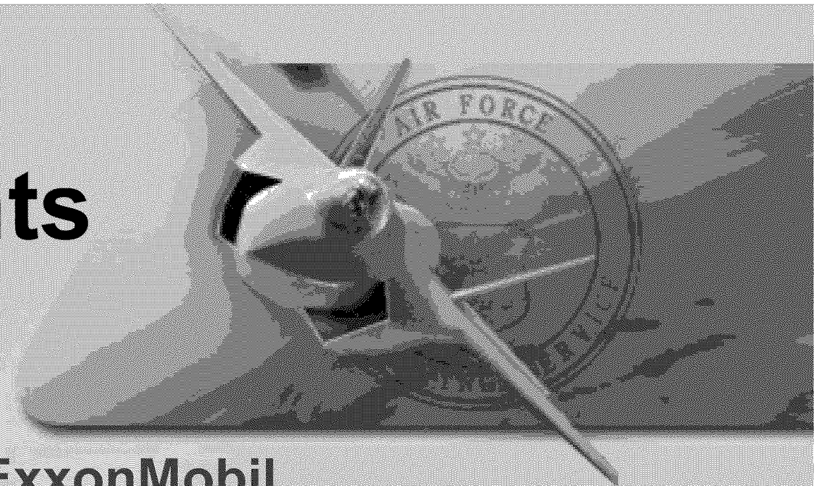
- **Lubrication performance with M-50 steel served as baseline comparison of the additives. 440C steel used to simulate advanced high-chrome bearing steels.**

Typical Elemental Composition of Selected Bearing Steels



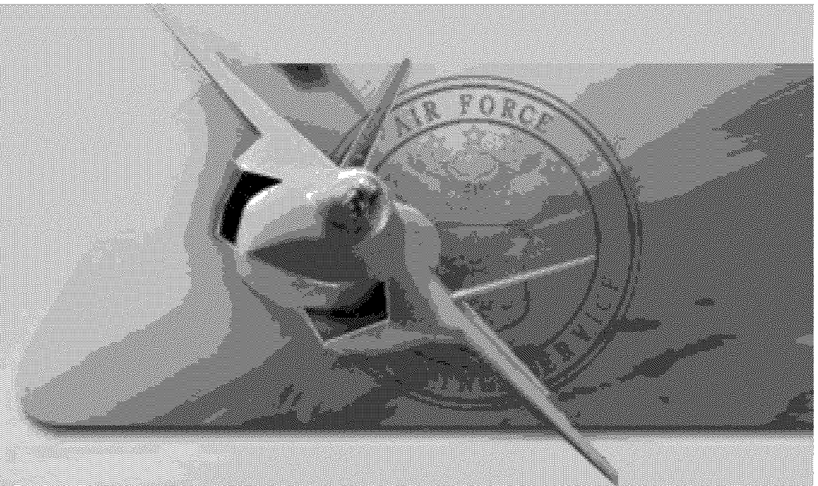
Material	Carbon %	Nitrogen %	Silicon %	Chromium %
52100	1.00	-	0.25	1.45
M50	0.80	-	0.25 max.	4.00
440C	1.10	-	1.00 max	17.0
Pyrowear 675	0.07	-	0.40	13.0
Cronidur 30	1.08	0.38	0.40	15.2

Industrial Participants



- Acheson Colloids
- Akzo Nobel
- Albemarle
- Chevron Texaco
- Ciba-Geigy
- Crompton
- Dover Chemical
- Elco Corporation
- Ethyl Corporation
- ExxonMobil
- Great Lakes Chemical
- King Industries
- Lockhart Chemical
- Lubrizol Corporation
- Rohm & Haas
- RT Vanderbilt
- Uniqema

Phase I Testing



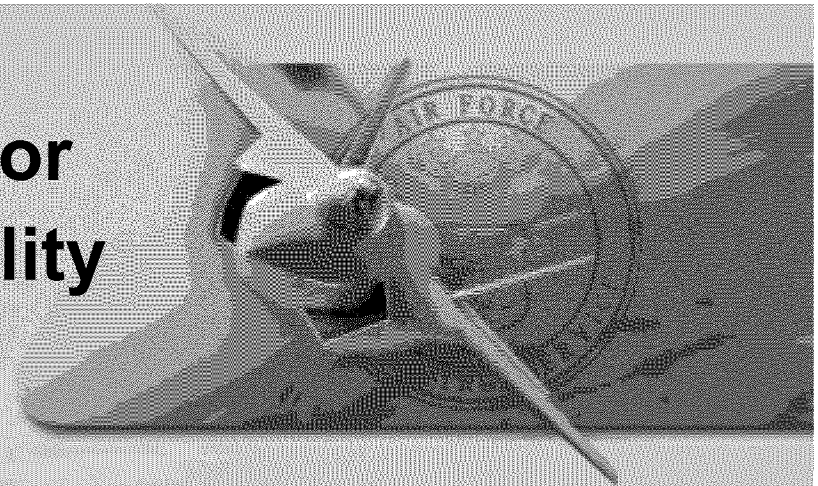
- Four Ball Wear Test
  - *Standard ASTM D4172 test conditions*
  - *Tests run on M50 and 440C steel balls.*
- Corrosion-Oxidation Stability
  - *MIL-PRF-7808L Requirements*
- Additive Solubility/Interaction
  - *active components from these formulations can have unexpected synergistic effects, which alter their original function.*

Additives tested at 2.0%

4-Ball Screening
Best Candidates

Formula Code	Lubricant Additive Chemical Description	Appearance @ 20°C	4-Ball Wear Scar, mm	
			M50	440C
A	ExxonMobil Polyol Ester Basestock (No Additives)	clear, colorless	1.14	test stopped
B	ExxonMobil RM284 Finished Fluid	dark brown	1.13	test stopped
1A20	Tricresyl Phosphate	clear colorless	1.27	3.28
9A20	Alkyl Phosphite Alkanolamine Borate Ester	cloudy, straw	0.40	**0.41**
10A20	Alkyl Phosphite Alkanolamine Ester	cloudy, straw	0.48	**0.40**
11A20	Isopropylated Triphenyl Phosphate	clear colorless	1.12	3.20
12A20	Proprietary Mixed Organophosphate Esters	clear colorless	0.54	2.62
23A20	Substituted Thiadiazole	clear, yellow	0.97	**1.28**

Formulations Evaluated for Corrosion-Oxidation Stability

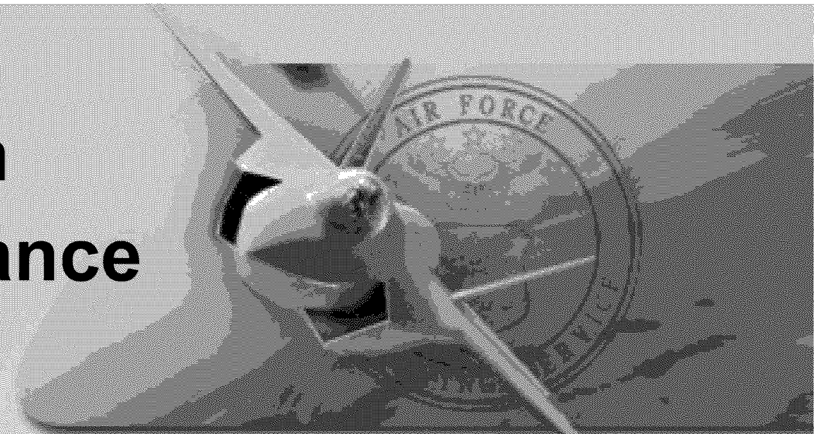


Formulation Components	B	10B20X1	AX2
ExxonMobil RM284 (B)	100.0	97.9	
Polyol Ester Basestock (A)			98.0
Additive 10		2.0	
Primene 81R		0.2	
PANA			1.0
DODPA			1.0

Corrosion-Oxidation Stability Data (96 Hours at 200°C)

Fluid Formulation	B	10B20X1	AX2
Viscosity @ 40C, cSt.			
Before	15.39	18.42	14.96
After	19.00	20.3	16.82
% Change (-5 to +18)	23.5	10.21	12.5
Viscosity @100C, cSt.			
Before	3.99	4.09	3.51
After	4.11	4.38	3.79
% Change (-5 to +18)	3.2	7.09	8.0
Neutralization No., mg KOH / g			
Before	0.07	3.65	0.01
After	0.91	6.68	0.90
Change (2.0 max)	0.84	3.03	0.89
Fluid Appearance	dark brown, no ppt	black	dark brown, deposit on tube
Sludge Volume, ml (none visible)	none visible	1.2	none visible
Weight Loss, % (4.0 max)	1.19	1.75	1.20

Effect of Antioxidant on Antiwear Additive Performance



Components	9A20		10A10		10A20		23A20	
Basestock A	97.8	95.8	98.9	96.9	97.8	95.8	98.0	96.0
Additive 9	2.0	2.0						
Additive 10			1.0	1.0	2.0	2.0		
Additive 23							2.0	2.0
Primene 81R	0.2	0.2	0.1	0.1	0.2	0.2		
PANA		1.0		1.0		1.0		1.0
DODPA		1.0		1.0		1.0		1.0
Four Ball Wear Scar Diameter, mm								
M50 Steel	0.40	0.42	0.44	0.47	0.48	0.45	0.97	0.98
440C Steel	2.37	**0.44**	1.72	**0.40**	1.83	**0.40**	1.28	1.85

Four Ball Wear Test Results of Best Candidate Formulations

Components	1A20X2.2	9A20X2.2	10A20X2.2	11A20X.2.2	12A20X2.2	23A20X2.2
Basestock A	96.0	95.0	95.0	96.0	95.9	95.0
PANA	1.0	1.0	1.0	1.0	1.0	1.0
DODPA	1.0	1.0	1.0	1.0	1.0	1.0
Primene 81R	-	1.0	1.0	-	0.1	1.0
Additive 1 (TCP)	2.0	-	-	-	-	-
Additive 9	-	2.0	-	-	-	-
Additive 10	-	-	2.0	-	-	-
Additive 11	-	-	-	2.0	-	-
Additive 12	-	-	-	-	2.0	-
Additive 23	-	-	-	-	-	2.0
Four Ball Wear Scar Diameter, mm						
M50 Steel	1.39	1.12	0.41	1.37	1.13	0.96
440C Steel	3.22	2.32	1.92	2.96	2.73	1.91

Addition of Antiwear Additives to Current Finished Fluid

Components	B	9B10X1	9B20X1	10B10X1	10B20X1	23B20
Basestock B	100.0	98.9	97.8	98.9	97.8	98.0
Primene 81R		0.1	0.2	0.1	0.2	
Additive 9		1.0	2.0			
Additive 10				1.0	2.0	
Additive 23						2.0
Four Ball Wear Scar Diameter, mm						
M50 Steel	1.13	0.42	0.46	0.48	0.57	0.96
440C Steel	Stopped	2.10	2.17	1.96	0.41	1.82

Corrosion-Oxidation Stability Data (96 Hours at 200°C)

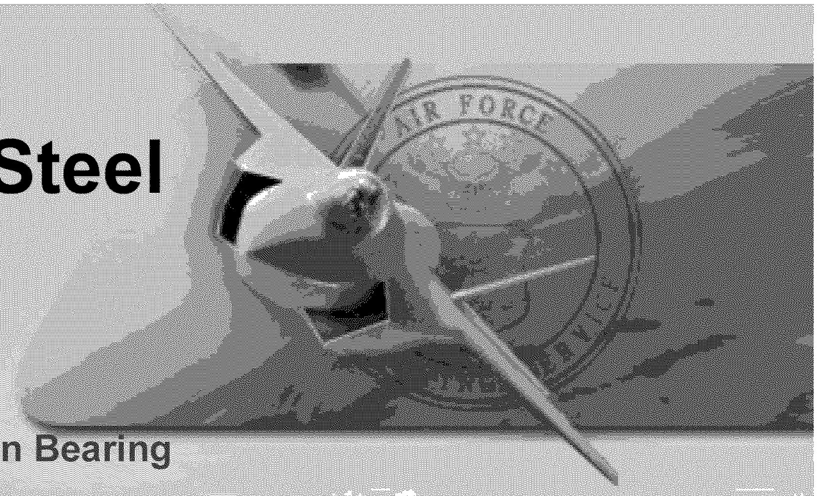
Fluid Formulation	1A20X2.2	9A20X2.2	10A20X2.2	11A20X2.2	12A20X2.2	23A20X2.2
Viscosity @ 40C, cSt.						
Before	15.10	15.19	15.35	15.24	15.21	14.56
After	16.81	18.10	18.47	17.10	17.31	16.97
% Change (-5 to +18)	11.3	18.6	20.4	12.2	13.8	16.5
Viscosity @100C, cSt.						
Before	3.52	3.56	3.55	3.53	3.53	3.56
After	3.79	4.07	4.04	3.83	3.82	4.00
% Change (-5 to +18)	7.7	14.1	14.0	8.6	8.1	12.3
Neut. No., mg KOH/g						
Before	0.01	1.12	2.74	0.03	0.01	0.56
After	0.66	3.39	3.88	1.22	0.57	2.72
Change (2.0 max)	0.65	2.27	1.46	1.19	0.56	2.16
Fluid Appearance	dark brown light ppt	black, heavy ppt	dark brown heavy ppt	dark brown no ppt	dark brown no ppt	dark brown heavy ppt
Sludge Volume, ml (none)	0.2	0.4	0.28	0.08	0.08	0.8
Weight Loss, % (4.0 max)	0.97	1.42	3.88	1.29	3.29	2.32

C-O Stability Data (96 Hours at 200°C)
Metals Appearance & Weight Change (mg/cm², max)

Formulation	1A20X2.2	9A20X2.2	10A20X2.2	11A20X2.2	12A20X2.2	23A20X2.2
Al (+/- 0.2)	0.00 light gray etch	+0.12 multicolor	-0.05 light gray	0.00 light gray	+0.03 lt gray	0.00 light gray
Ag (+/- 0.2)	0.00 light gray etch	+0.22 multicolor	+0.10 multicolor etch	-0.03 light gray	0.00 lt gray	+0.09 black
Bz (+/- 0.4)	0.00 brown etch	+0.02 multicolor	+0.20 brown etch	-0.02 brown	-0.05 brown	-0.78 multicolor etch
Fe (+/- 0.2)	+0.02 multicolor etch	+0.08 dark brown	+0.07 multicolor etch	-0.02 multicolor	0.00 dark blue	+0.14 dark brown
M50 (+/- 0.2)	+0.03 multicolor etch	+0.12 dark brown	+0.20 dark gray etch	+0.03 multicolor	-0.02 light gray	+0.14 multicolor
Mg (+/- 0.4)	+0.03 light gray etch	-1.16 multicolor etch	+0.15 multicolor	0.00 light gray	+0.03 light gray	+0.15 multicolor
Ti (+/- 0.2)	+0.02 multicolor	+0.26 dark brown	+0.02 dark gray	-0.02 gray	0.00 gray	+0.10 multicolor

Wear Testing of Advanced Steel

Ball-On-3-Disk Method



Cronidur 30 steel disk samples prepared by FAG/Barden Bearing

- **Laser-cut slices from rod stock**
- **Prepared to surface finish representative of that of bearing race**

M50 and 440C ball rotating against Cronidur 30 disks

Best Candidate Lubricant Formulations						
Components	**1A20X2.2**	**9A20X2.2**	**10A20X2.2**	**11A20X.2.2**	**12A20X2.2**	**23A20X2.2**
Four Ball Wear Scar Diameter, mm						
440C Steel Ball on Cronidur 30 Steel Disks						
40 Kg Load	Stopped in < 1 min. Squealing	Stopped in < 1 min. Squealing	Stopped in < 1 min. Squealing	Stopped in < 1 min. Squealing	Stopped in < 1 min. Squealing	Stopped in < 1 min. Squealing
5 Kg Load	Stopped in < 1 min. Squealing	Stopped in < 1 min. Squealing	Stopped in < 1 min. Squealing	Stopped in < 1 min. Squealing	Stopped in < 1 min. Squealing	Stopped in < 1 min. Squealing
M50 Steel Ball on Cronidur 30 Steel Disks						
5 Kg Load	0.34	---	0.27	0.40	0.32	---
40 Kg Load	2.28	---	1.91	1.34	2.03	---

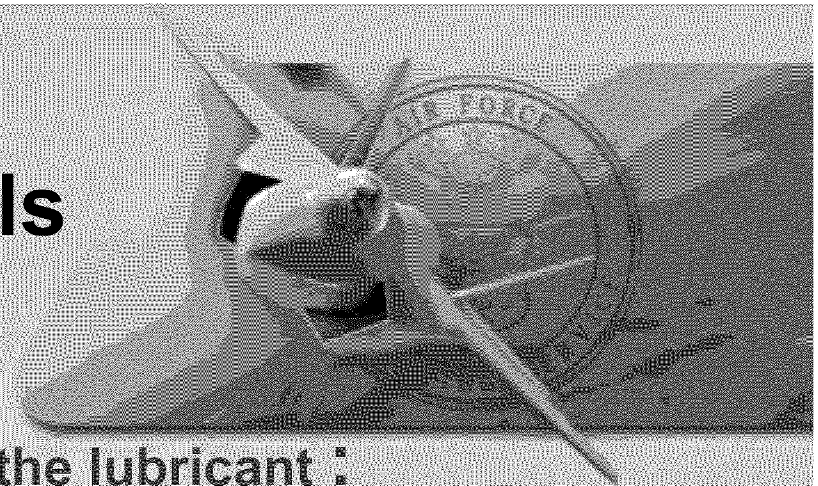
Accomplishments to Date

- METSS has identified 5-6 different lubricant additives that exhibit better antiwear properties on conventional (M50) as well as high-chrome (440C) steels than the current additive used in existing GTOs.

- Two of the best antiwear candidates also exhibited the thermo-oxidative stability and low corrosion rates required of GTOs high temperature service conditions.

- The results of the Phase I program clearly demonstrated the technical feasibility of developing product formulations to meet the program requirements and provide a solid foundation for Phase II development

Phase II Program Goals

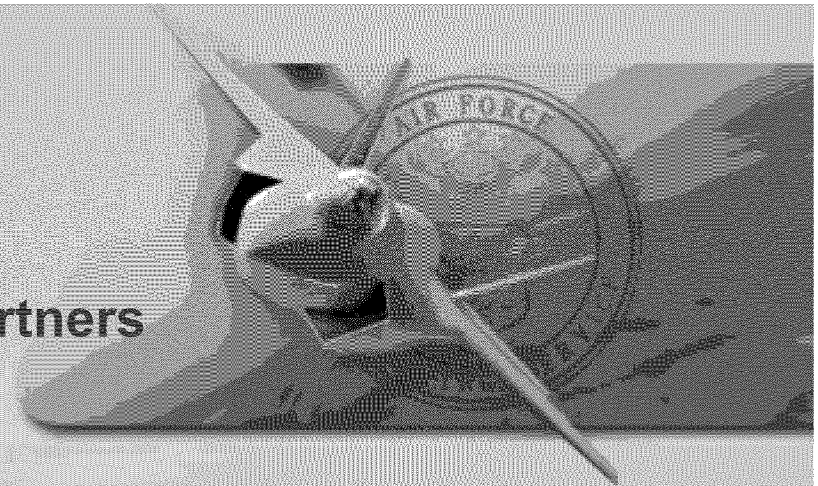


- METSS will demonstrate the ability of the lubricant :
  - *to meet all applicable performance specifications*
  - *to address issues of environmental concern*
  - *materials developed to meet field service requirements*
  - *technology to be transition to near-term military and industrial uses, and commercial market applications.*

The program will create an opportunity for new GTO lubricant additives for DoD and support future materials development efforts.

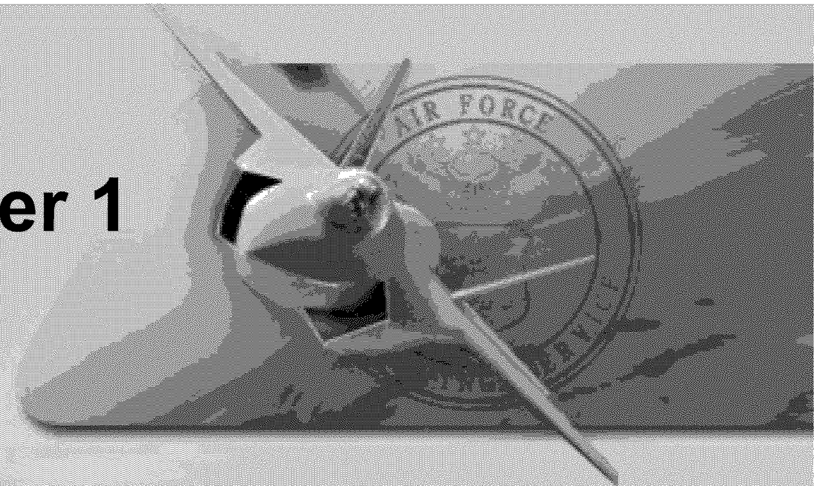
- *The best overall lubricant candidate developed during Phase II will be subjected to full qualification testing by approved third party laboratories in accordance with the requirements of the MIL-PRF-7808 Grade 4 fluid specification.*

Phase II Partners



- SBIR program commercialization partners
  - *Nyco America*
  - *Hatco Corporation*
  - *Timken*
  - *The Valvoline Company*
- Outside testing laboratories
  - *Phoenix Chemical*
  - *UEC*
  - *NAVAIR*
  - *UTC*
  - *Timken Technical Services*
  - *Wedeven Associates*
- Commercial suppliers of bearing steels
- Commercial suppliers of specialty additives
- Commercial suppliers lubricating oils and base stocks.

Testing and Evaluation - Tier 1



- Testing and evaluation
  - *Physical and Chemical Properties*
  - *Mixture Compatibility*
  - *Four Ball Wear Testing*
    - **ASTM D4172 - the relative antiwear properties**
    - **determination of coefficient of friction**
    - **ball-on-disk configuration to evaluate the friction wear properties of the candidate lubricant formulations on the advanced steels**
      - **test matrix will include friction and wear testing of the advanced steel disks in conjunction with M50 and 440C steel balls, as well as ceramic silicon nitride ball.**

Phase II Tier 2 Testing

- Corrosion-Oxidation Stability (Federal Test 791c 5308.7)
  - *determines the ability to resist oxidation and tendency to corrode various metals*
- Coking Tendency(ASTM D3711)
  - *determines the tendency to form coke deposits in contact with surfaces at elevated temperatures*
- Additional Tribology Testing
  - *an attempt at correlating laboratory friction and wear performance with anticipated performance in the field*
    - ***Falex Ring-On-Block Test***
    - ***WAM Testing***
    - ***Other Advanced Testing***

SBIR Topic AF03-119

Gas Turbine Engine Oil Additives for Advanced Bearing Steels

Military Aviation Fluids and Lubrication Workshop

June 15-17, 2004

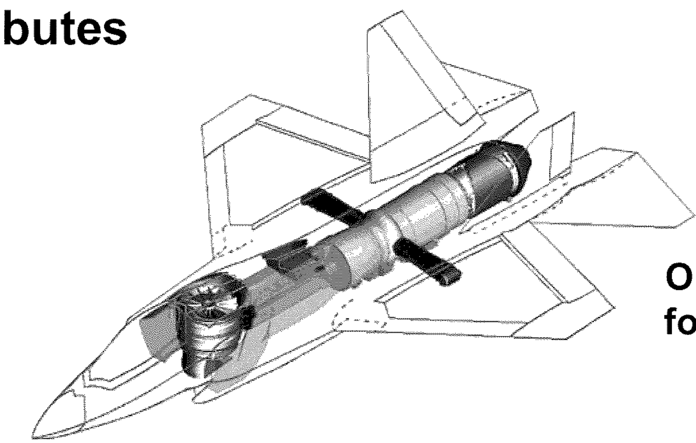
Vern Wedeven
Wedeven Associates, Inc.

Small Business Innovative Research (SBIR)
U.S. Air Force Contract No. F33615-03-M-5024
Program manager: Lois Gschwender

Objectives

Phase I Objective

Feasibility to significantly enhance boundary lubrication of advanced corrosion resistant materials without loss of other oil attributes



Goal
Oil additive technology
for engine and gearbox

Briefing Outline

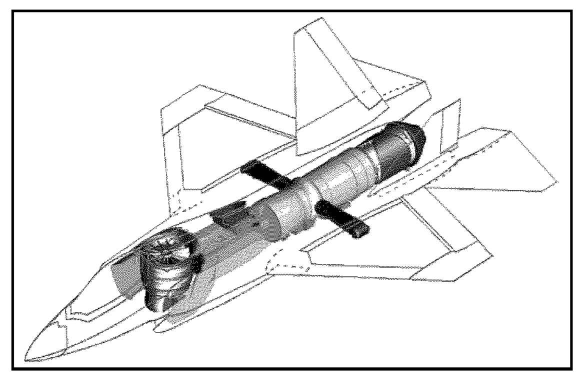
- Background: risk in new oils and bearing materials
- Phase I approach and results
- Phase II plans

Trends in New Oils and Bearing Materials

Material → Fatigue resistance, corrosion resistance
Less wear resistance

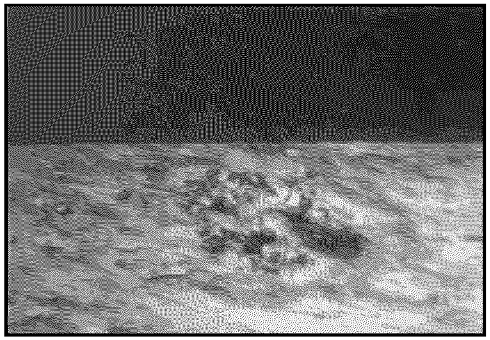
Oil → High thermal stability (& corrosion inhibited)
Less chemically active for boundary lubr.

History: Independent & parallel R&D
Insufficient test methods
Severe tribology risk

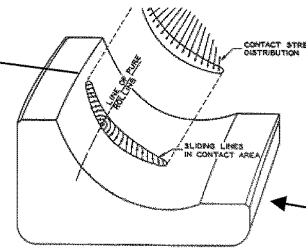


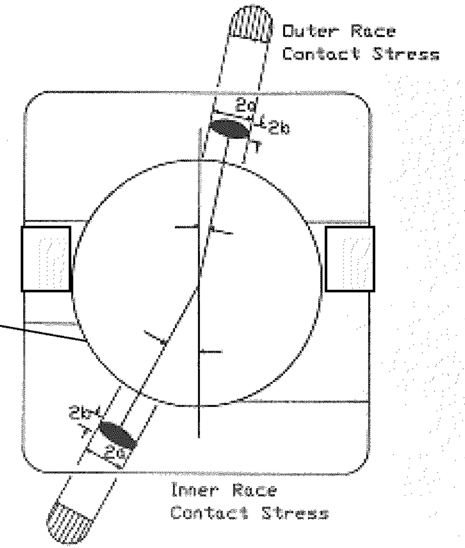
Risk in New Oils and Bearing Materials

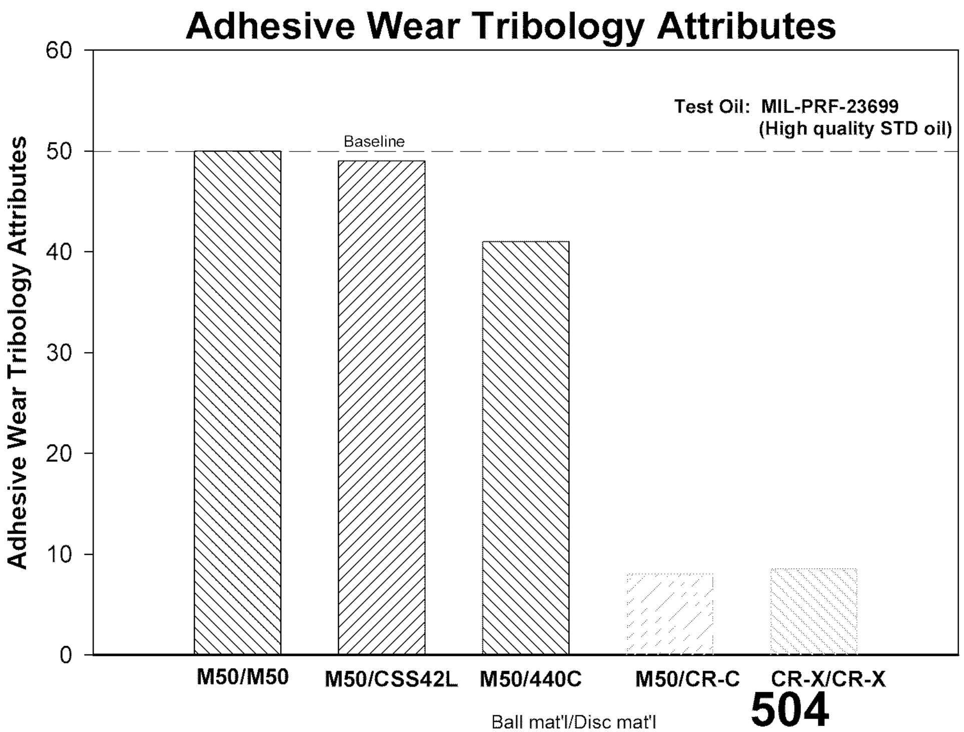
Late 1990s – move toward corrosion resistance



Adhesive wear with CR-C material





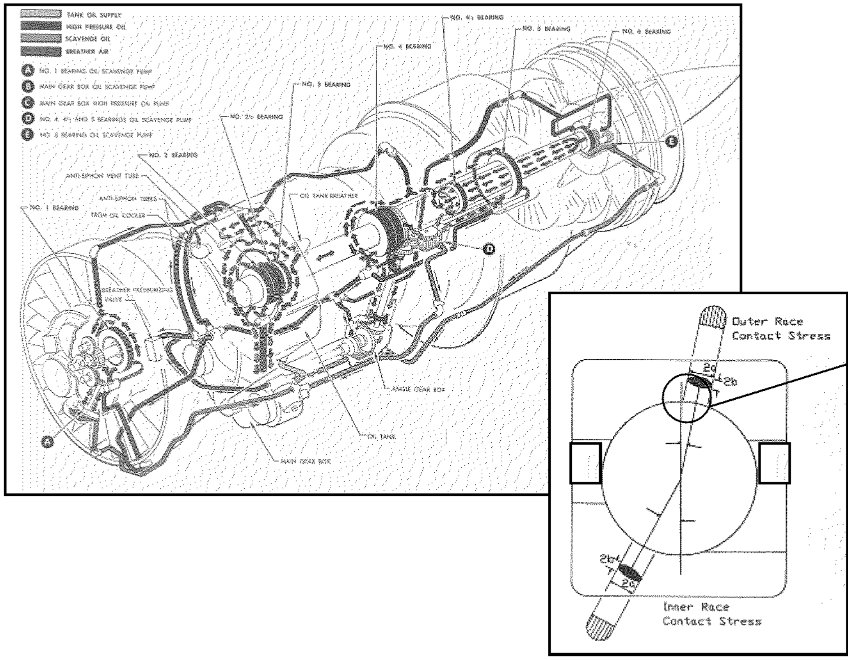


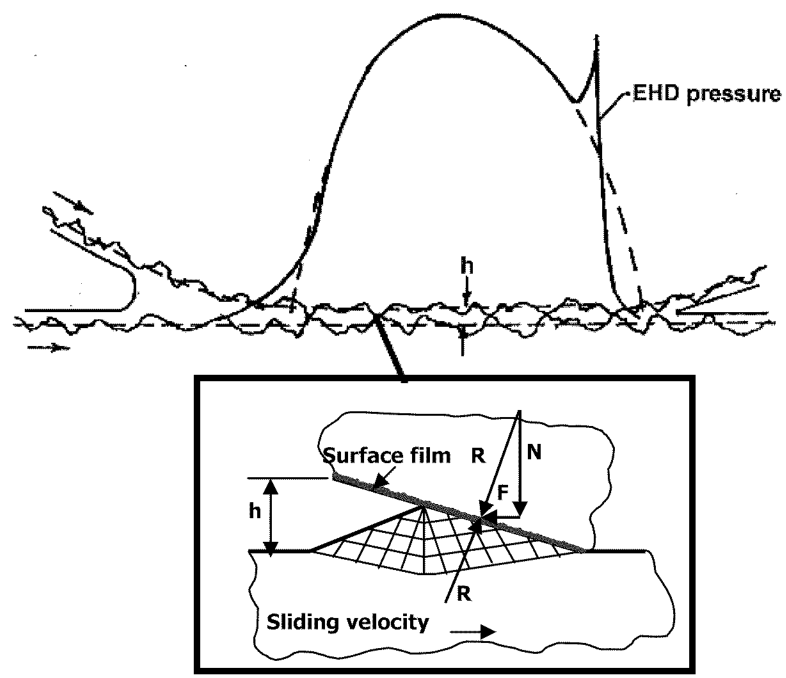
Some corrosion resistant & fatigue resistant materials have poor resistance to adhesive wear

Must screen all tribology attributes before committing to implementation

Risk in New Oils and Bearing Materials

1980s -1990s reduced active chemistry for boundary lubrication





Oil Technology Drivers:

High Thermal Stability (HTS) oils

Corrosion Inhibited (CI) oils - Navy

Reduced Fe at surface & less active oil chemistry inhibits surface film formation for boundary lubrication

Risk in New Oils and Bearing Materials

Background & Conclusions

Bearing materials:

Demand for fatigue life and corrosion resistance
has made bearing surfaces more difficult to lubricate

Engine Oils:

Demand for thermal stability & corrosion inhibition has
reduced oil active chemistry for lubr. of bearing surfaces

Need: (Urgent)

Lubricating additive technology for new JSF materials

Leave no attribute behind

Strategic Approach

Utilize:

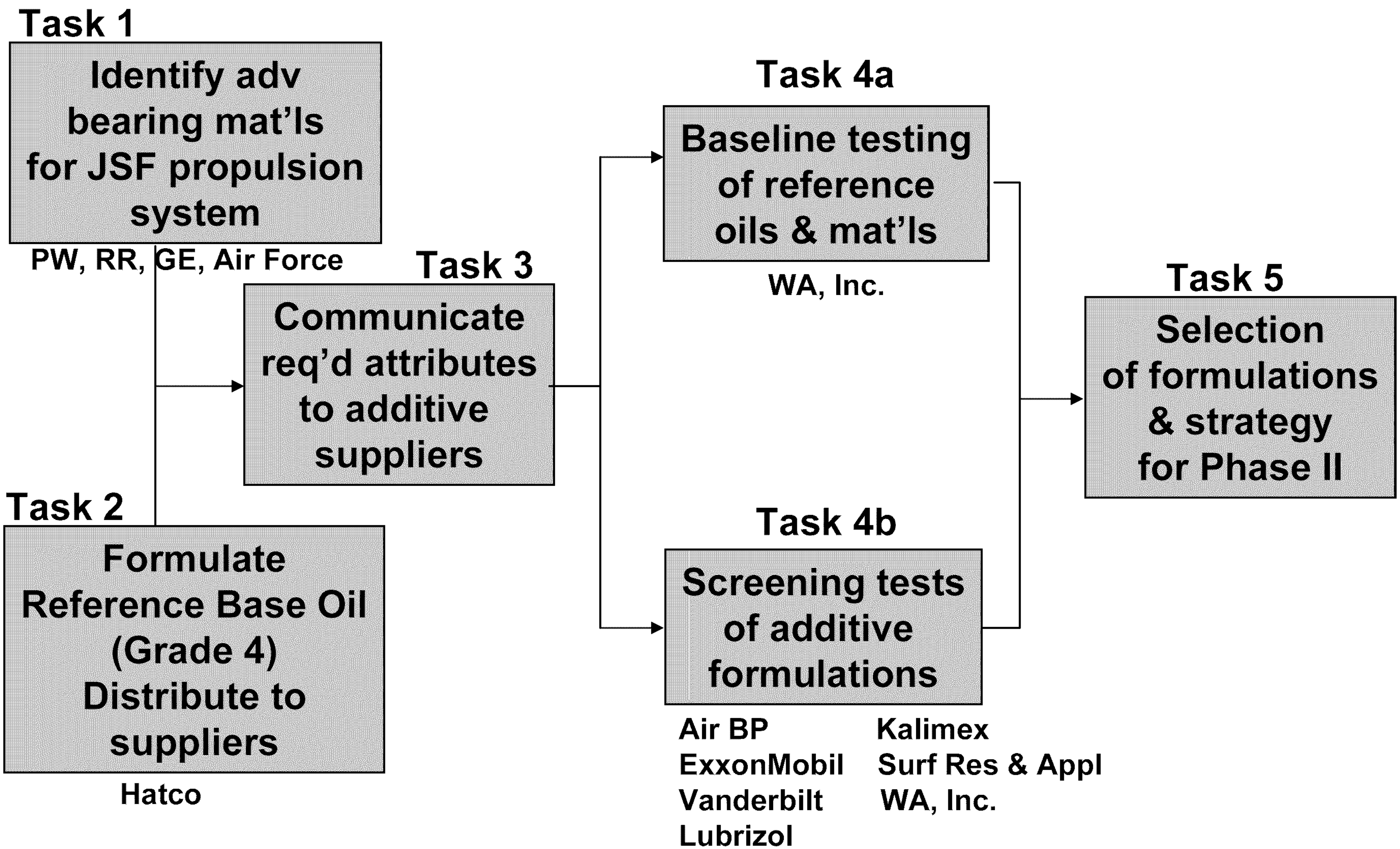
WA, Inc. assets - test methods, close association with aviation oil/chemical suppliers, specification authorities and users –
Catalyst to affect change

Suppliers (Air BP, ExxonMobil, Vanderbilt, Lubrizol, Surf Res, others)
-formulation skills, business motivation and resources for production, marketing and distribution
Must have pathway to market for success

Leverage -

Related efforts – Air Force SBIR Phase II (test methods); PW/RR Lift Fan for JSF (corrosion resistant bearing/gear materials): Sikorsky RDS-21 (testing adv bearing mat'l/lubes)
U*nderstanding of needs (oils, materials, designs)*

Technical Approach

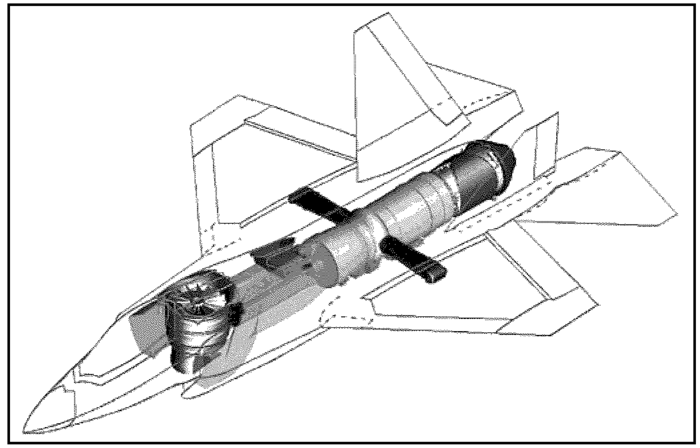


Technical Approach

Task 1

Identify adv bearing mat'ls for JSF propulsion system

PW, RR, GE, Air Force



Candidate CR Bearing & Gear Steels – Phase I

Pyrowear 675 – heat treatment not quite ready

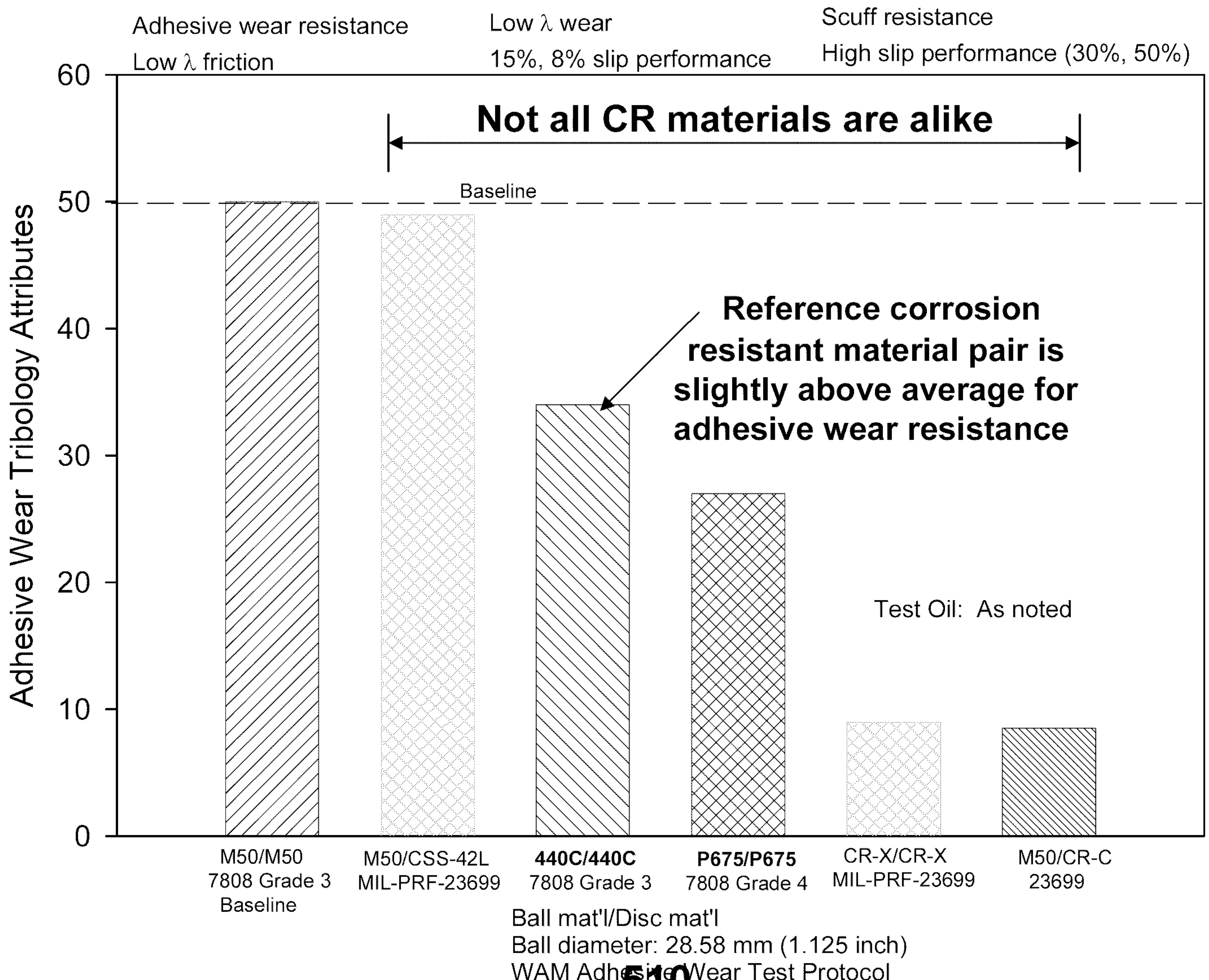
Cronidur 30 – adhesive wear risk

CSS-42L – not sufficiently mature

440C – selected as reference mat'l for Phase I

Technical Approach

Adhesive Wear Tribology Attributes



<<Adhesive Wear.jnb>>

Technical Approach

Ref Oil: Grade 4 (TEL-0004) - Air Force recommendation

Ref. Base Oil: Hatco - Tom Schaefer formulation HXL-7597

Properties

Vis @ 100 C	4.04 cSt
Vis @ 40 C	17.70 cSt
Spec Gr	0.955
Pour pt	-62 C
Flash pt	243 C

Task 2

Formulate Reference Base Oil (Grade 4)
Distribute to suppliers

Hatco

Base stock (TMP)	
HXL-7598 (Lot H23366)	97.95%
Antioxidant	
• DODPA (Vanlube V-81)	1.0%
• Alkylated PANA (Ciba L-06)	1.0%
Yellow metal corrosion inhibitor	
Benzotriazole	0.05%

Technical Approach

Reference Base Oil HXL-7597 Distribution

(Lot H23365)
30 gal batch

Task 2

Formulate Reference Base Oil (Grade 4) Distribute to suppliers

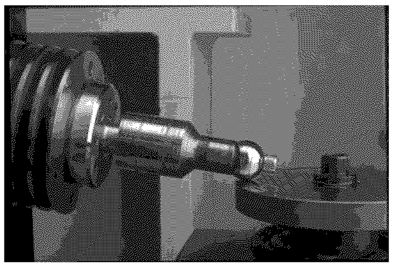
Hatco

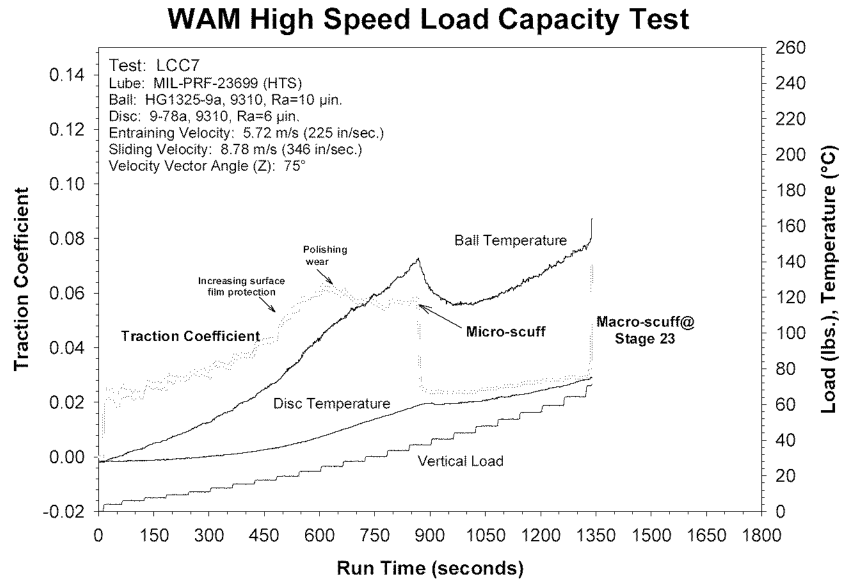
Air BP	5 gal
Vanderbilt	5 gal
Lubrizol	3 gal
ExxonMobil	-
WA, Inc.	5 gal
→ Kalimex	(5 gal base stock)
→ Surf Res & Appl 5 qts	
U.S. Air Force	1 gal (1 gal base stock)

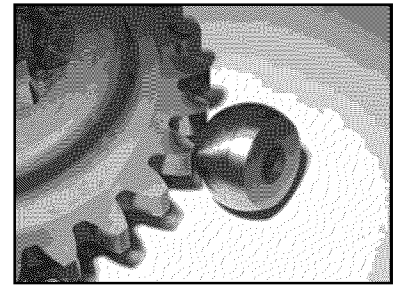
Screening Test Method

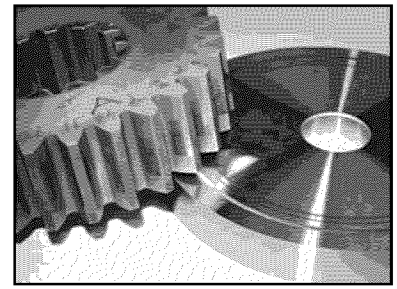
Task 4

Screening tests of additive formulations







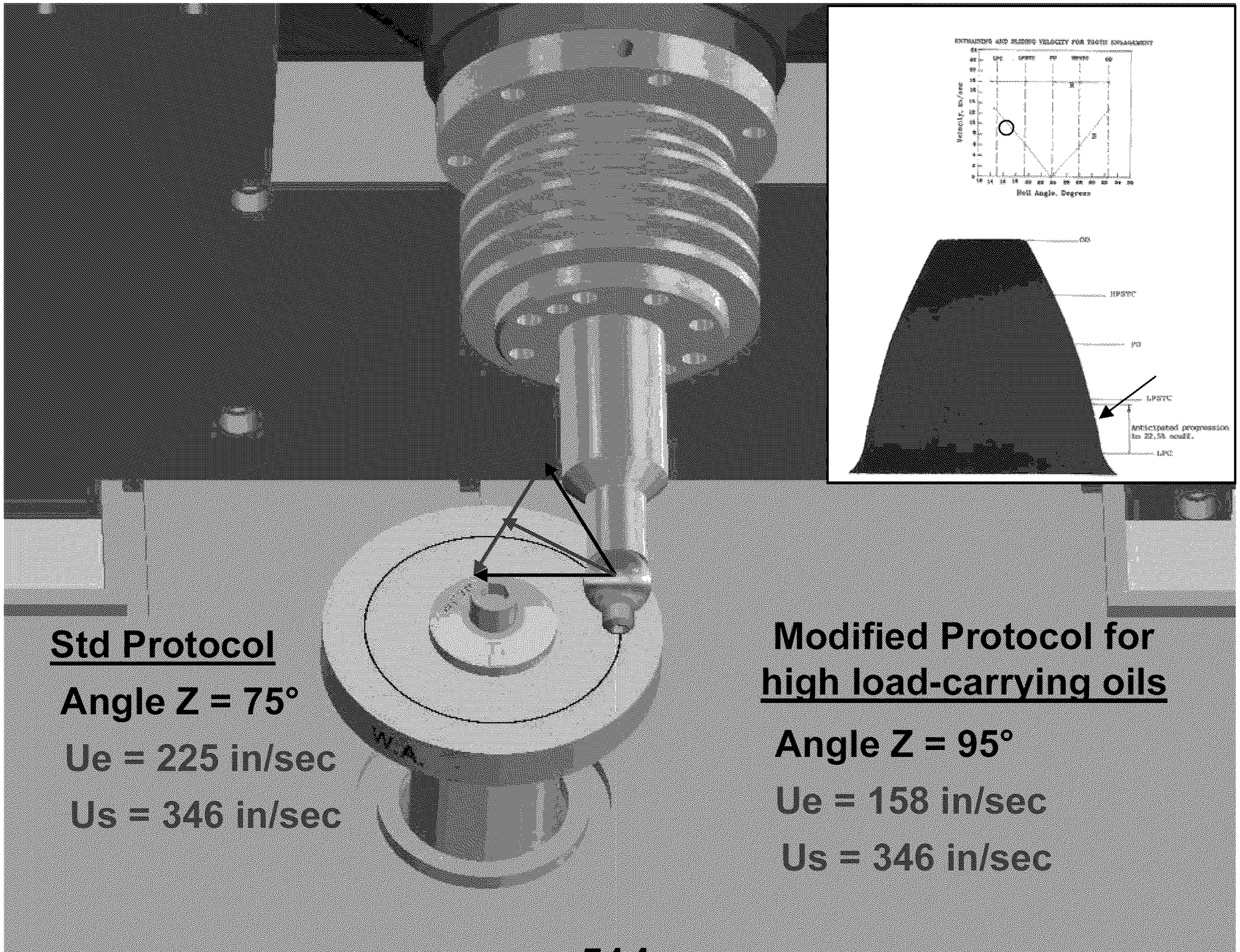


WAM High Speed Load Capacity Test Method

- Developed for U.S. Navy (linkage to Ryder Gear)
- Evaluates wear & scuffing over large temperature range
- Confidence with oil suppliers, spec authorities and engine companies
- SAE E-34 approval
- Extensive database with linkage to service performance
- Cost effective and quick turn-around

WAM High Speed Load Capacity Test

Ryder Gear simulation at point of scuffing initiation

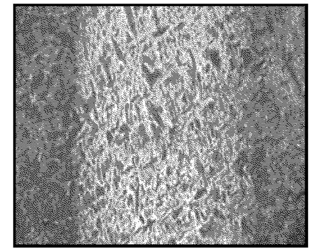


Screening Test Method

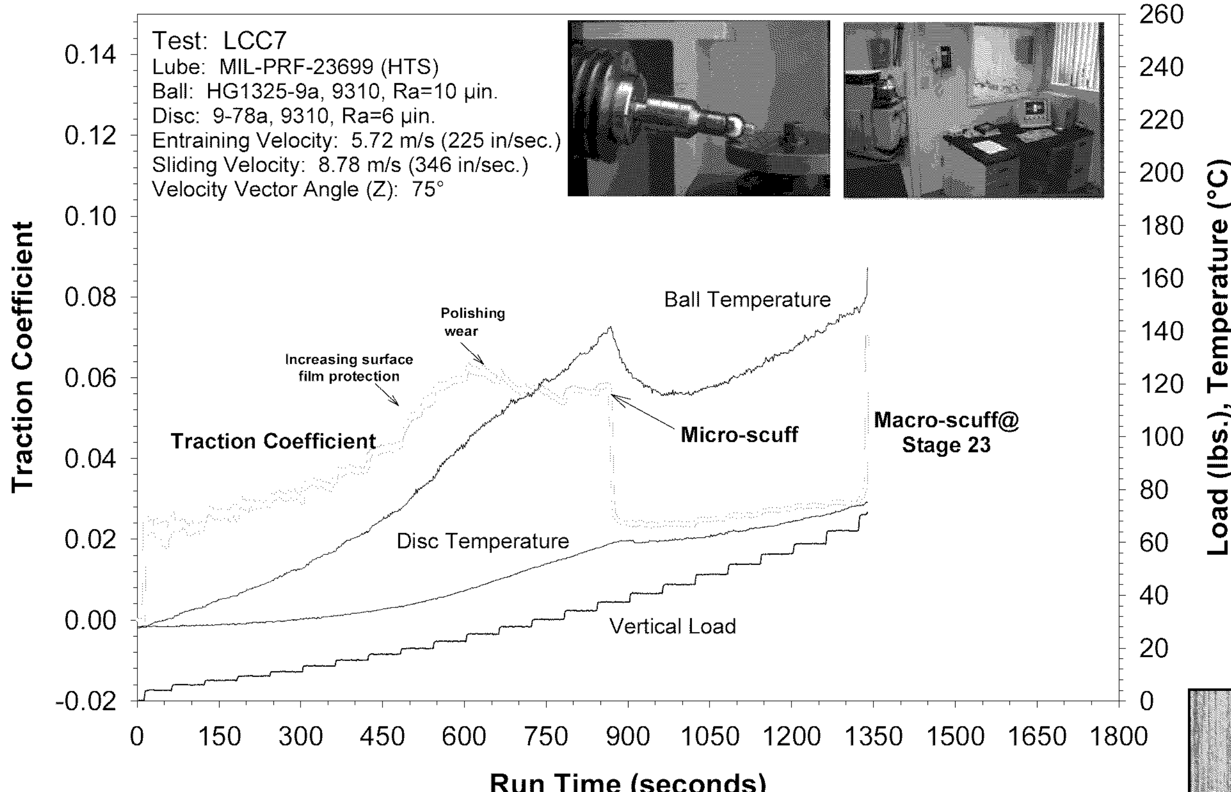
Modify with Stainless Steel Mat'ls: 440C/440C

- Traction behavior & boundary lubrication

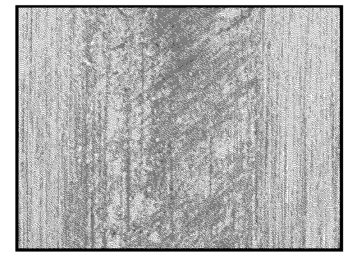
- Polishing wear



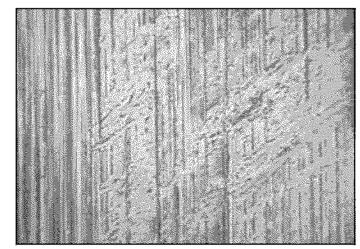
WAM High Speed Load Capacity Test



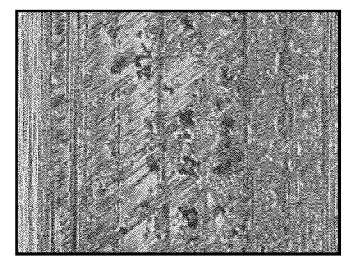
- Surface film



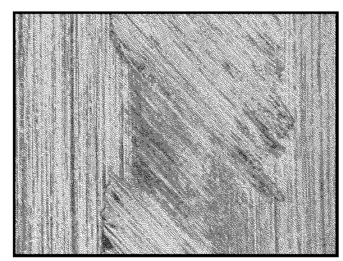
- Micro-scuffing



- Micro-pitting

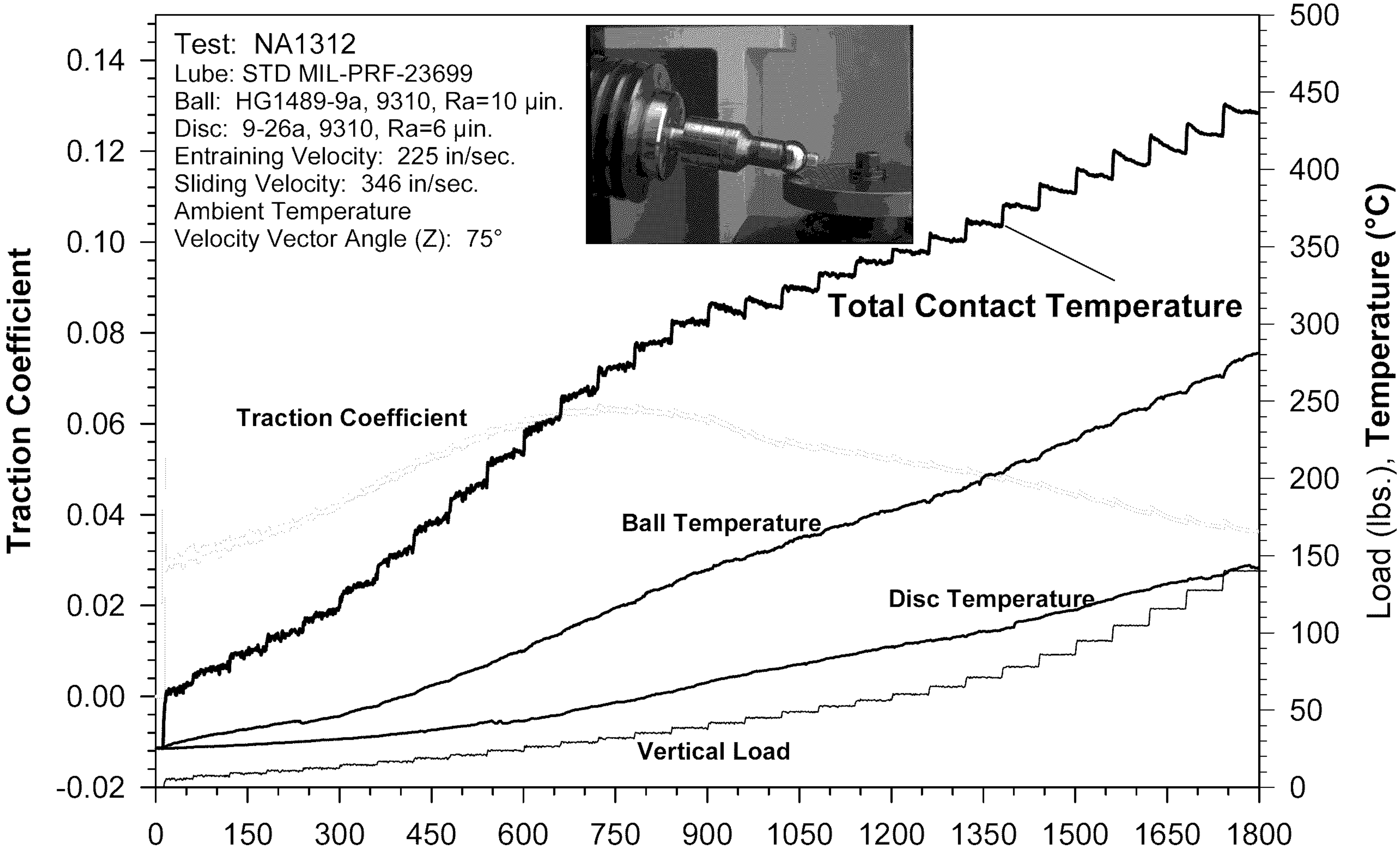


- Scuffing



Technical Approach

Calculated Total Contact Temperature



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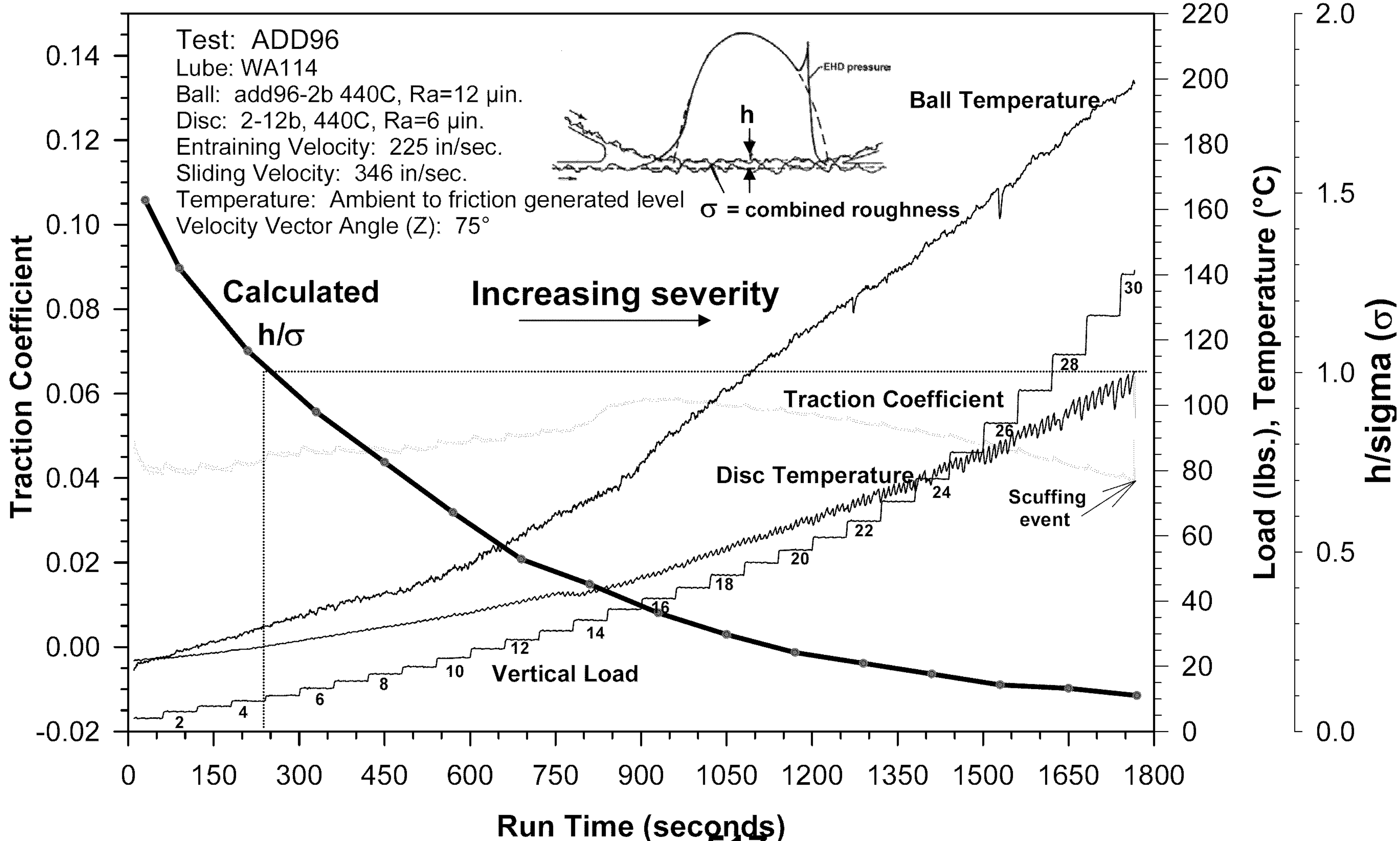
Technical Approach

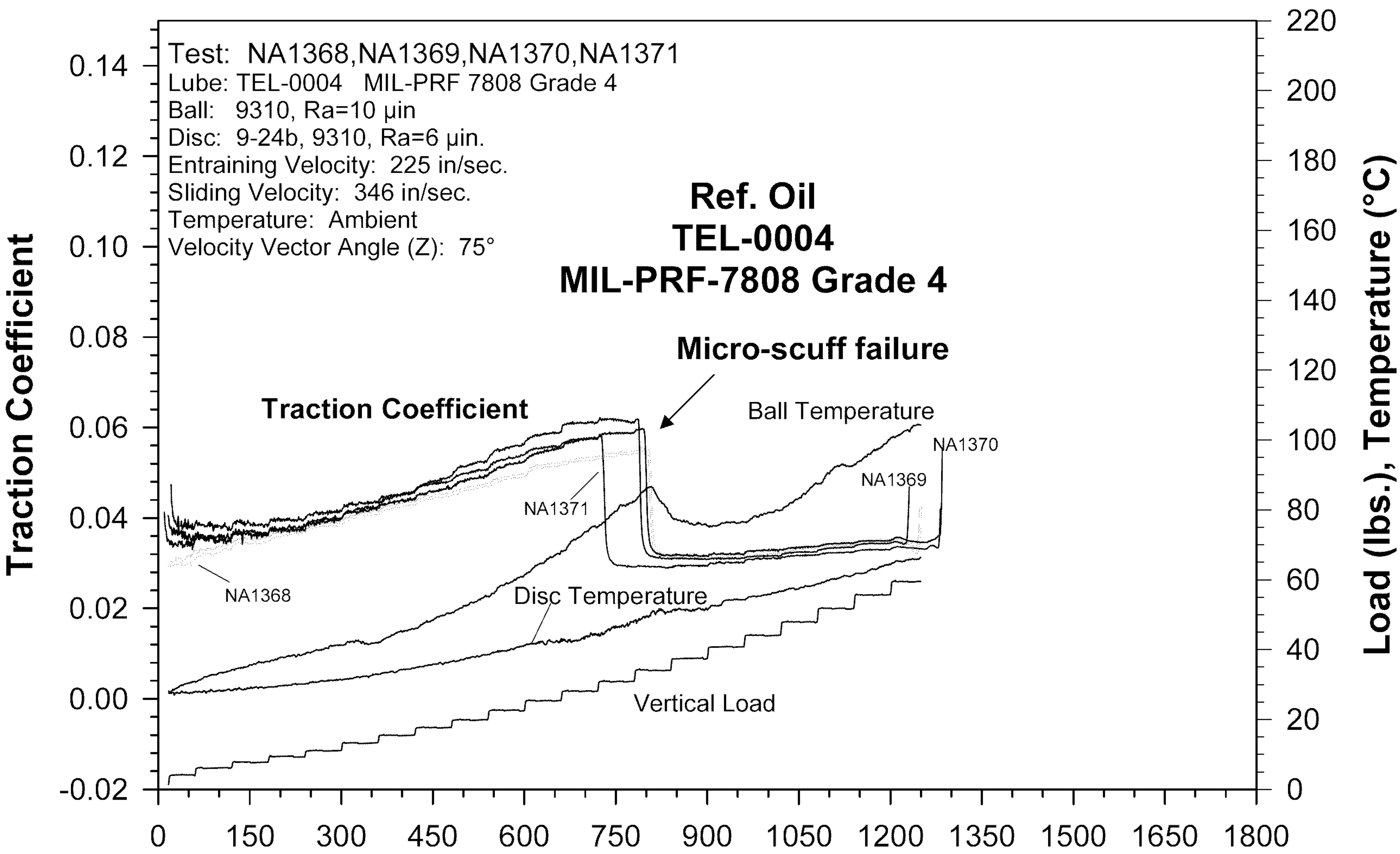
Loading protocol affects temperature and reduces h/σ

WAM Screening Test Method with 440C materials



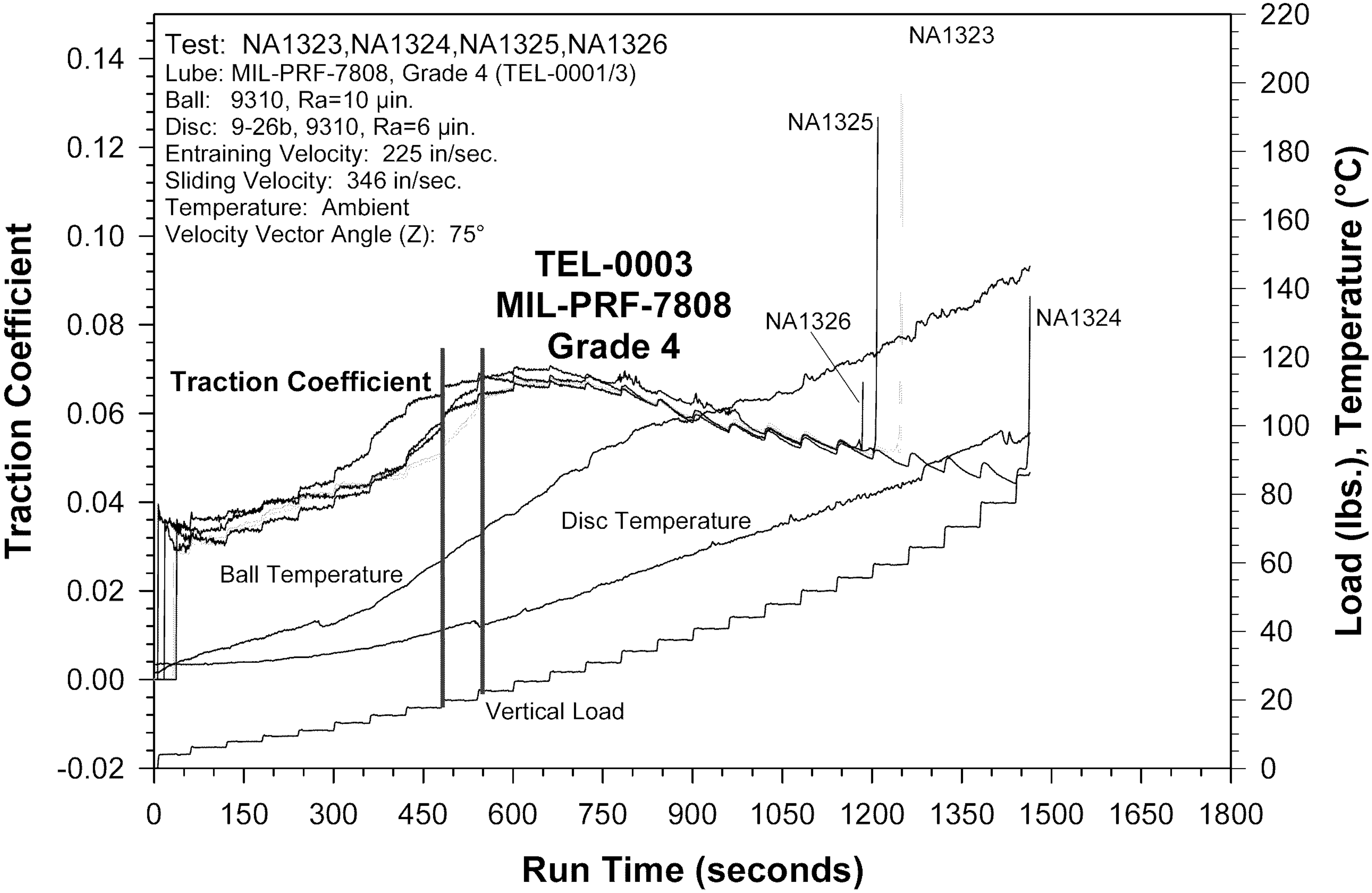
Four Test Determinations

Good repeatability



Data Processing

Average TC for each load stage



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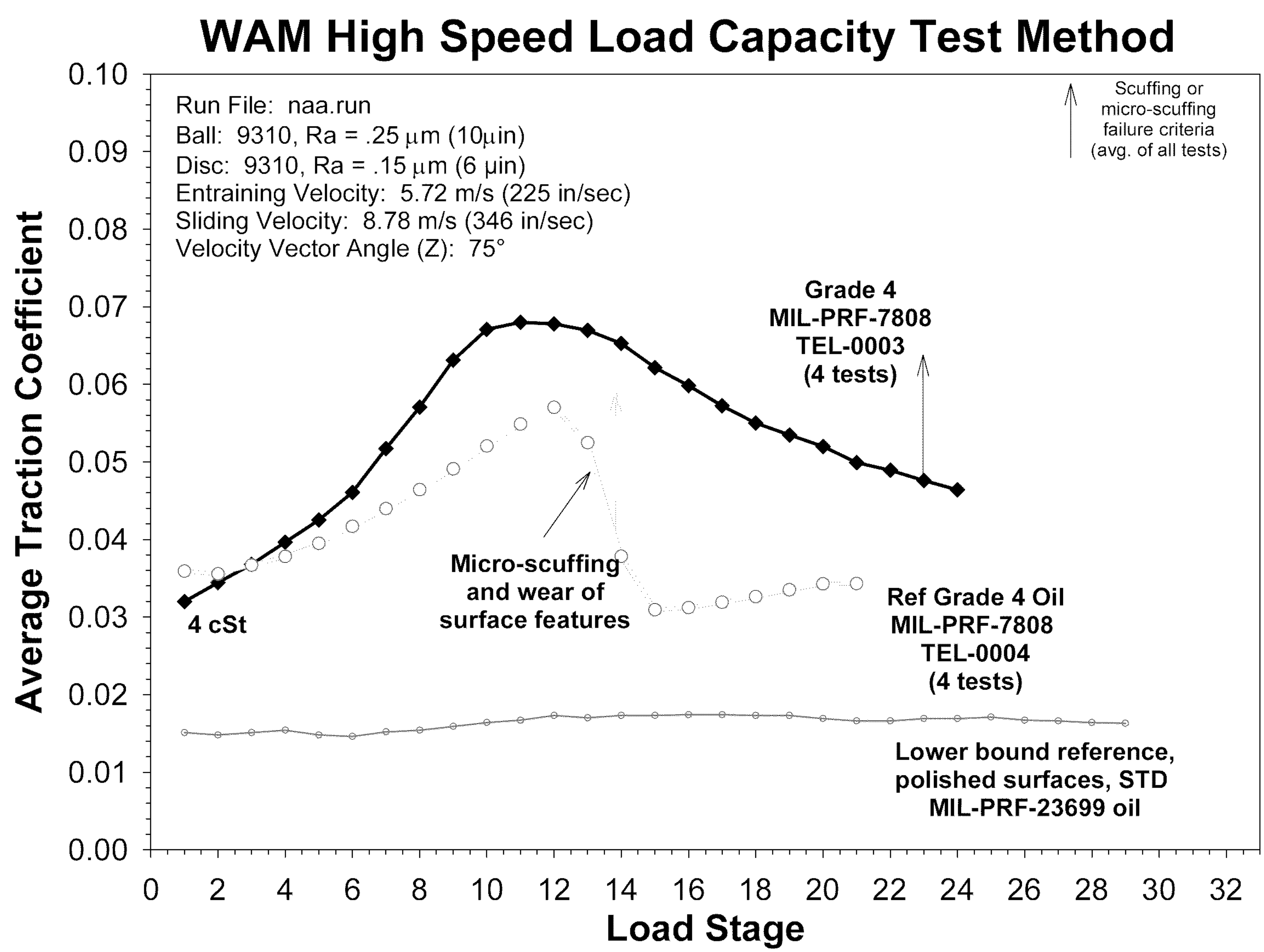
Traction and Scuffing Behavior

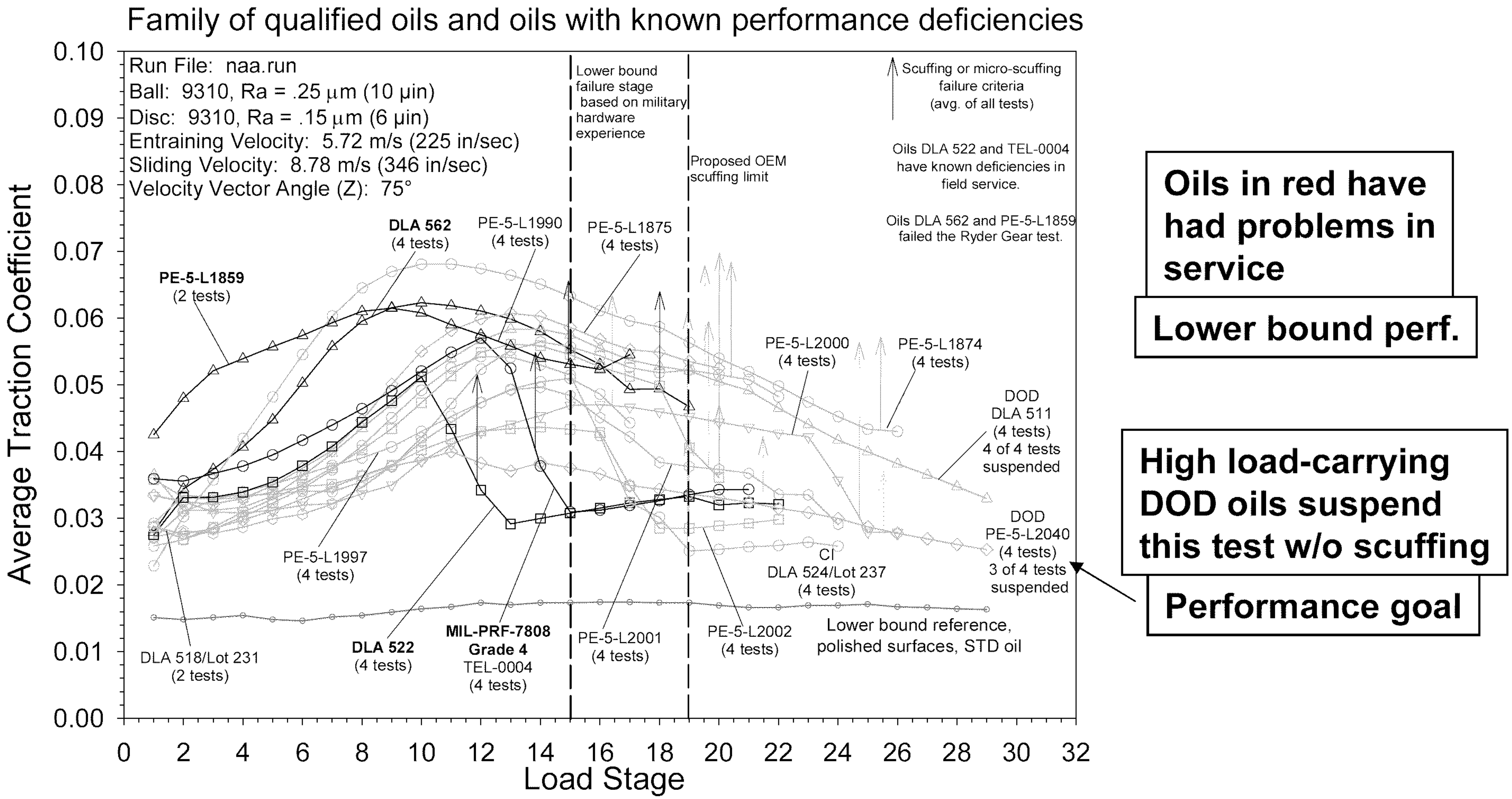


Qualified U.S. Air Force Grade 4 Oils

520

Linkage to Service Performance

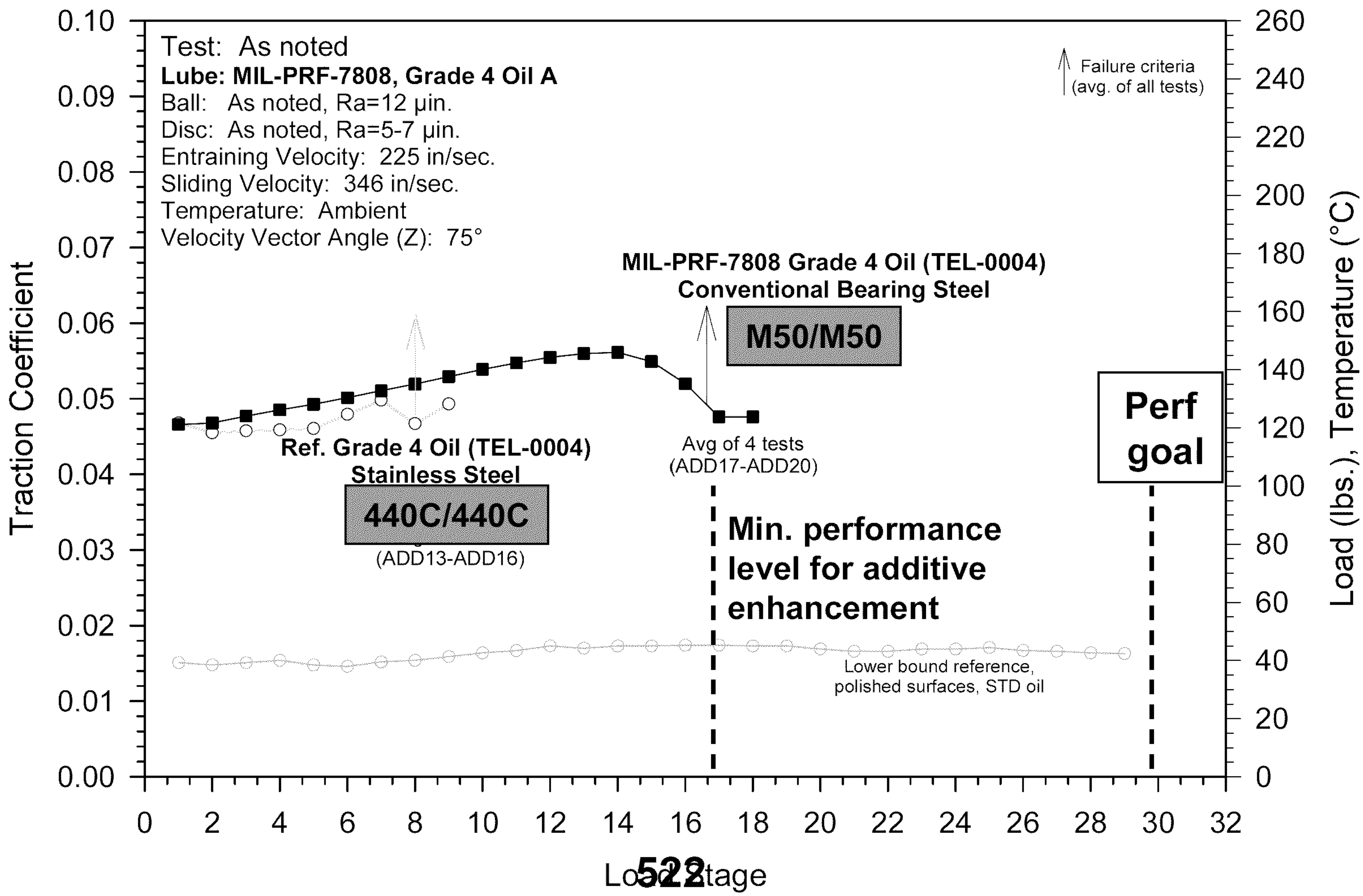
WAM High Speed Load Capacity Test Method



Baseline Tests with Ref Materials

Reference MIL-PRF-7808 Grade 4 Oil (TEL-0004)

WAM High Speed Load Capacity Test Method



522

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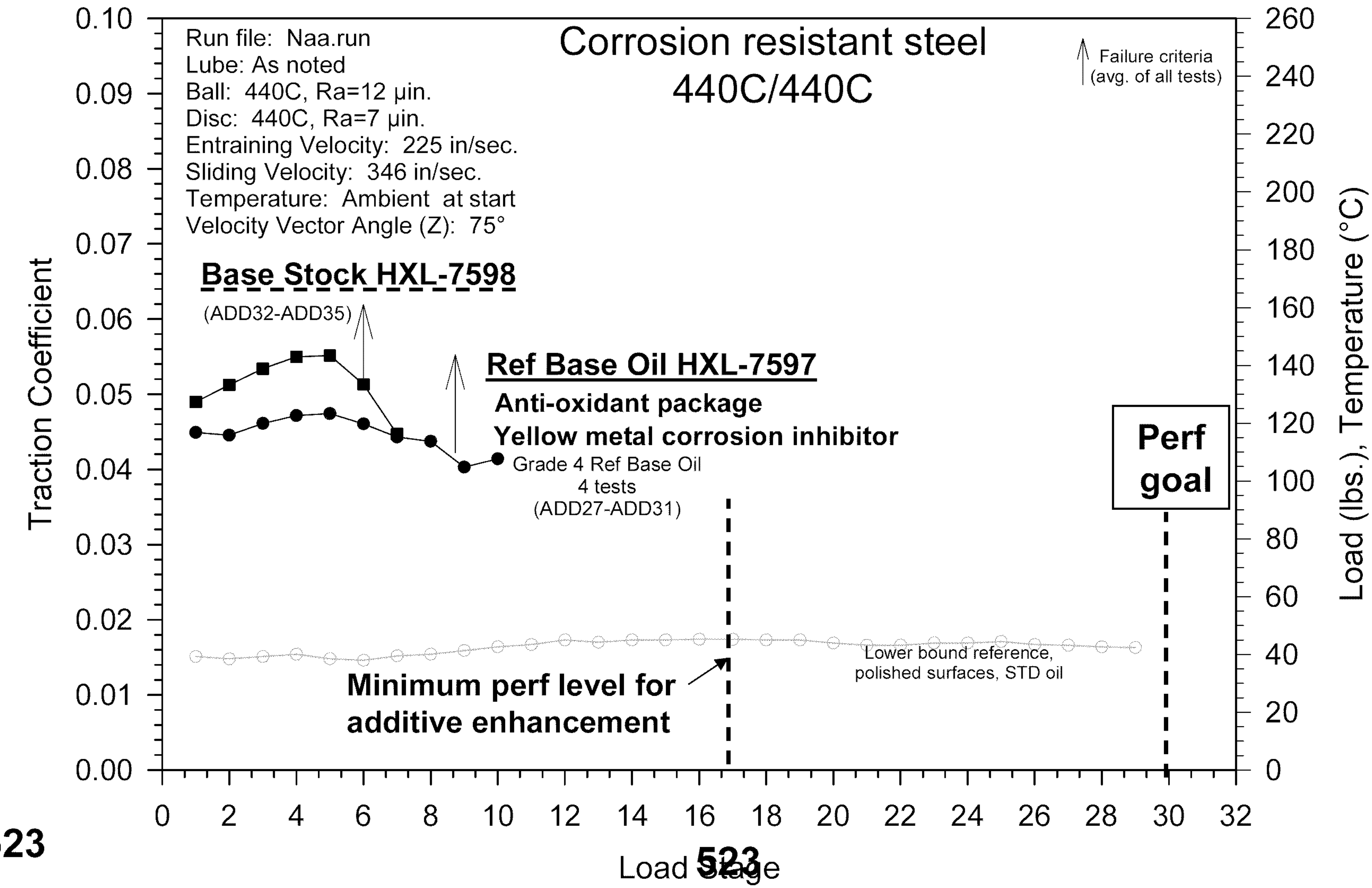
Reference Base Oil & Base Stock

WAM High Speed Load Capacity Test Method



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Screening Test Process

Std protocol with 440C materials

↓ Down-selection

Check for backward compatibility with M50 materials

↓

Modified protocol with 440C materials

↓

Follow-on strategy for Phase II

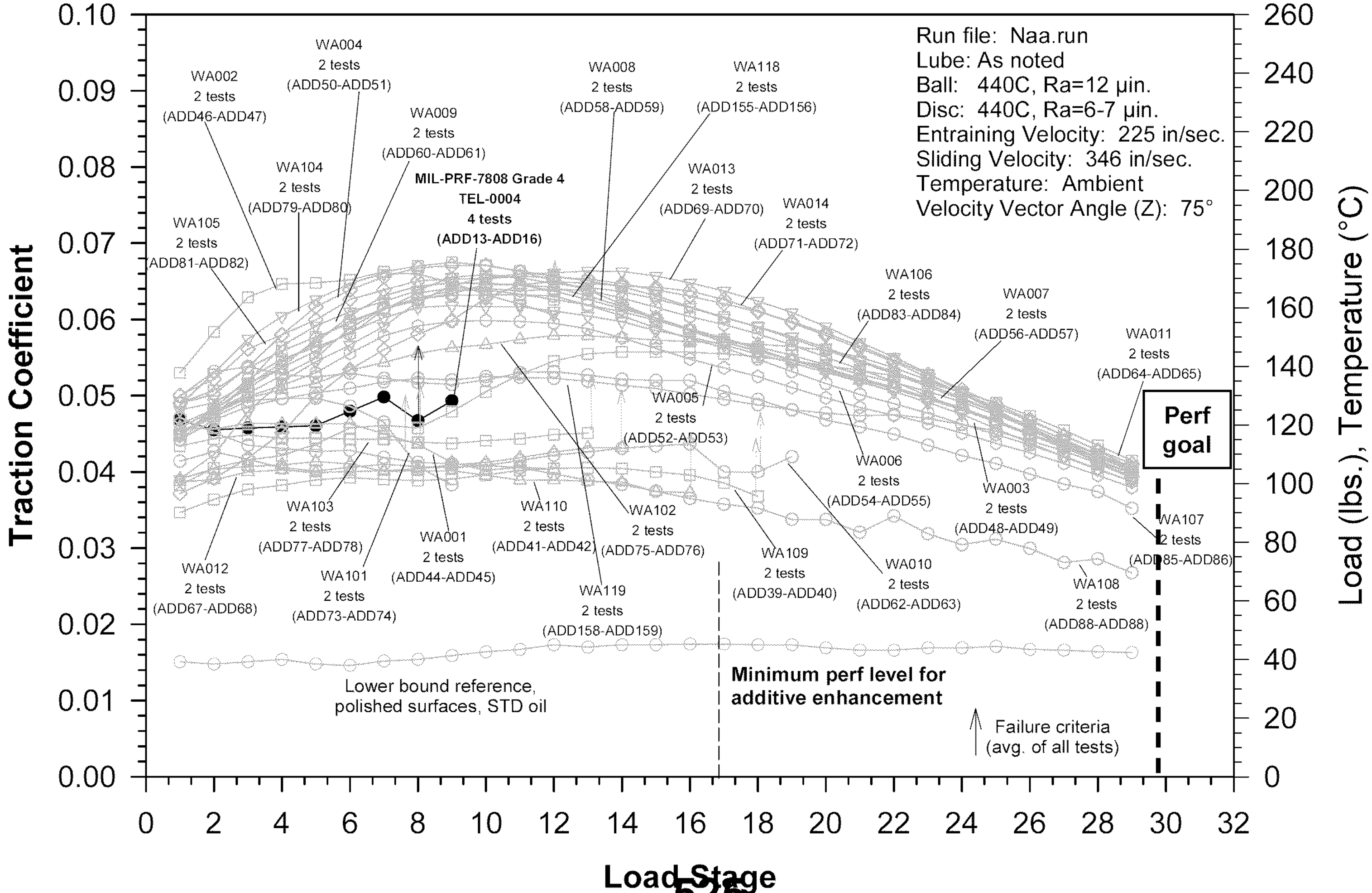
No. of formulations: 60

No. of tests: ~200

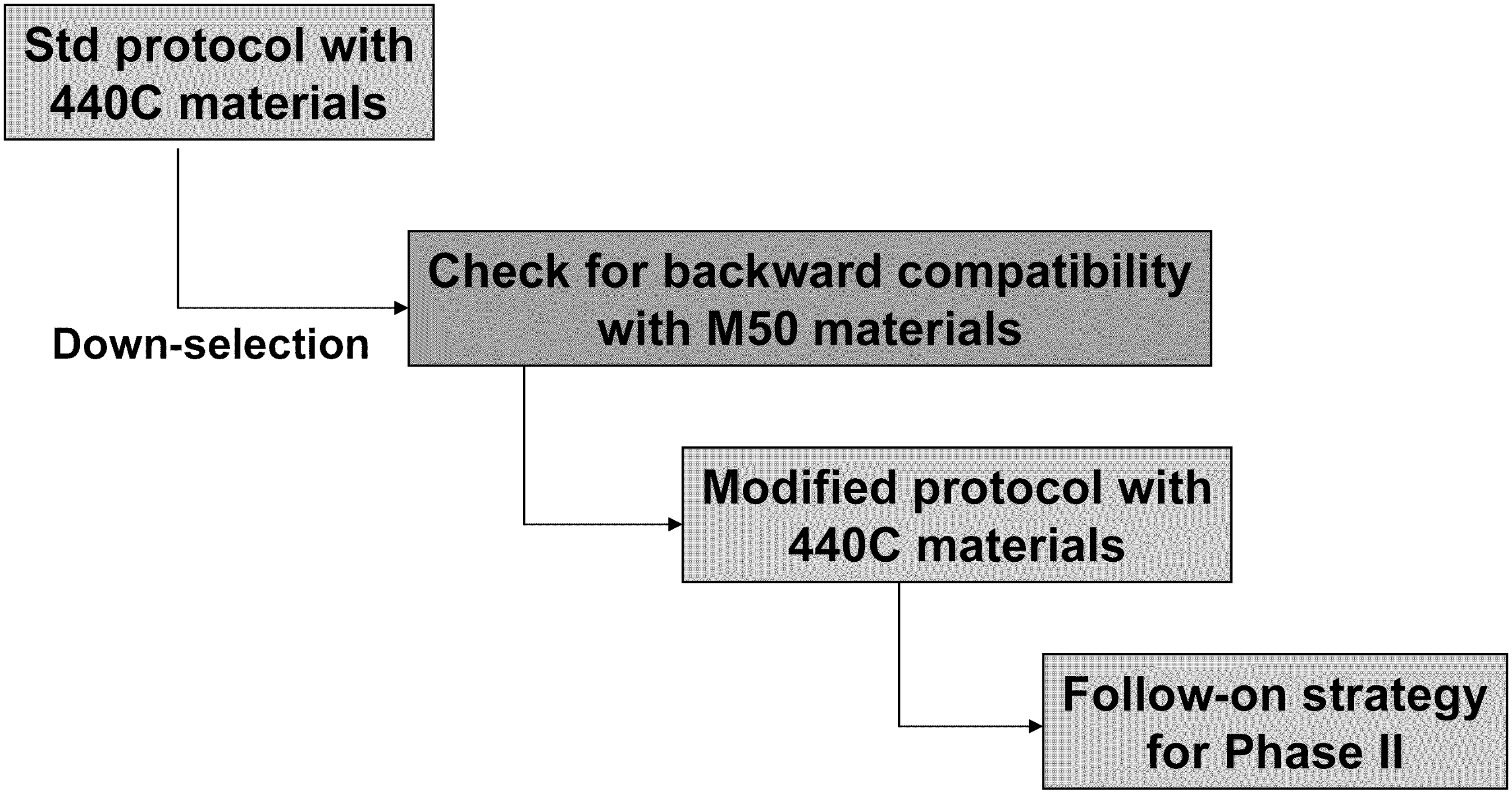
Dec 2003

Monster Graph of Standard Protocol Tests

- **All key suppliers have at least one formulation that suspends the standard protocol without a scuffing event, even with 440C materials!**
- **Variation in traction reflects range of boundary lubrication chemistry**

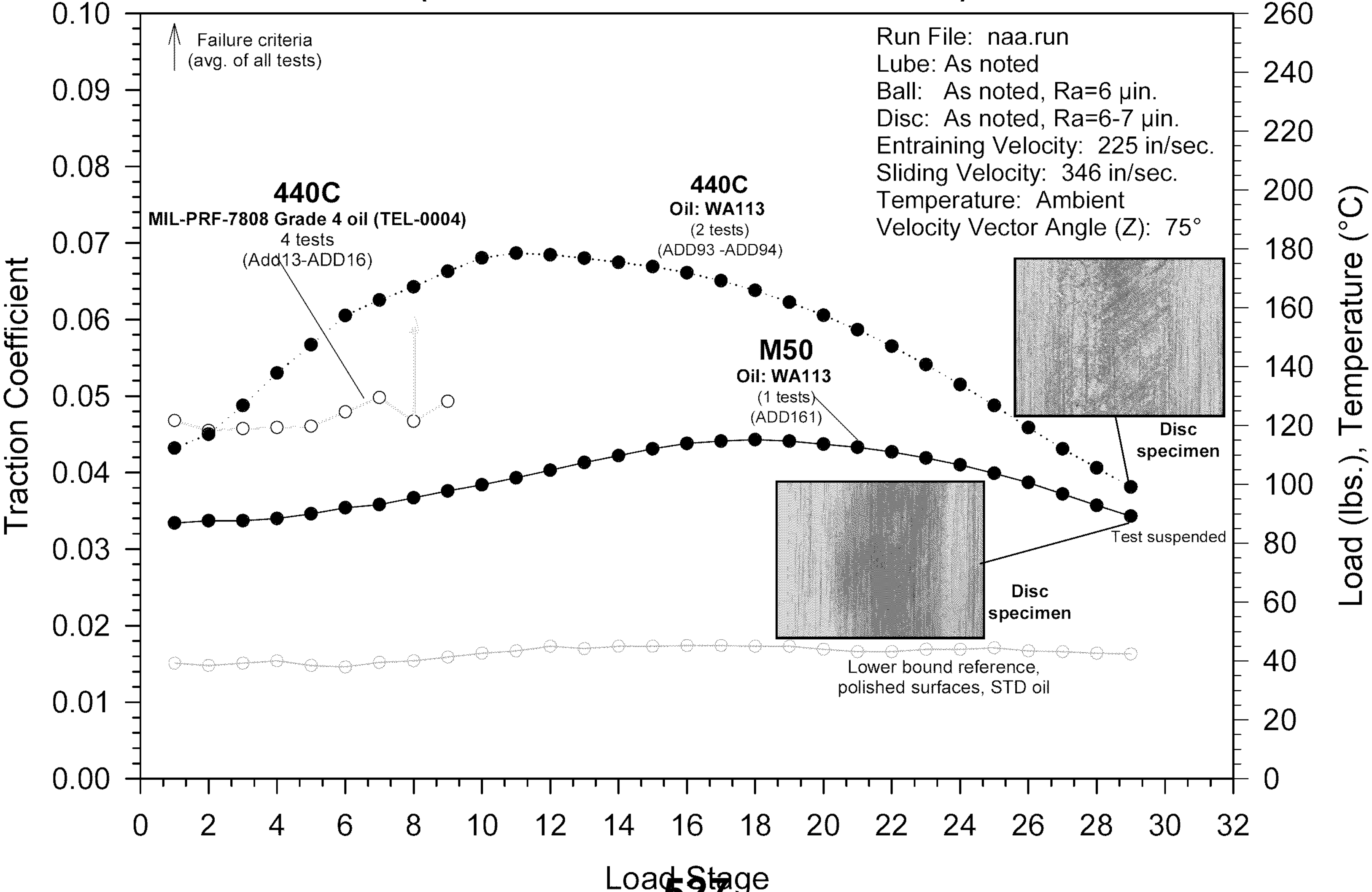


Screening Test Process



Backward Compatibility with M50

Lower traction coefficient with M50 implies greater polishing wear than with 440C
(True for all formulations tested)



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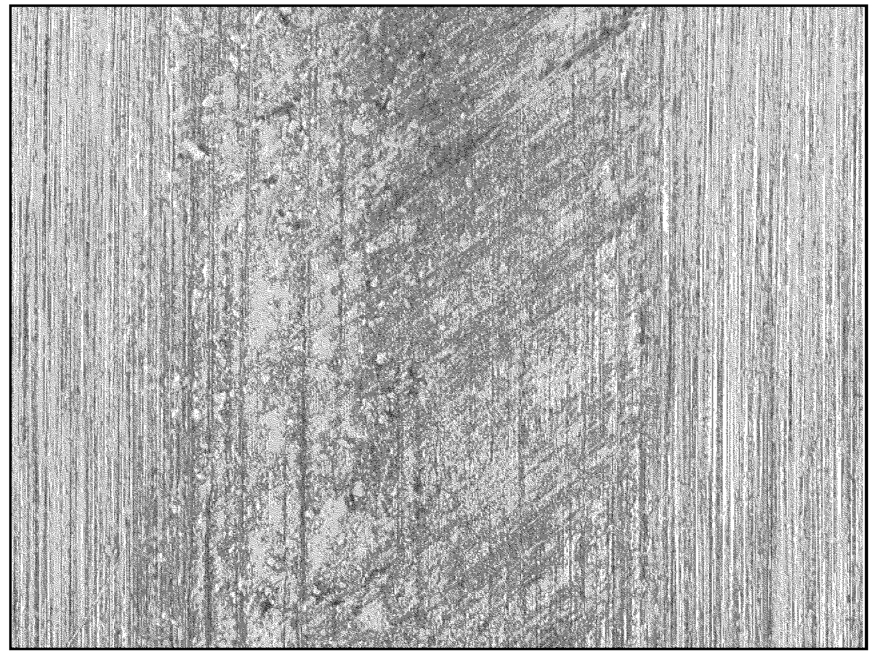
Backward Compatibility with M50

Lower traction coefficient with M50 implies greater polishing wear or better run-in than with 440C

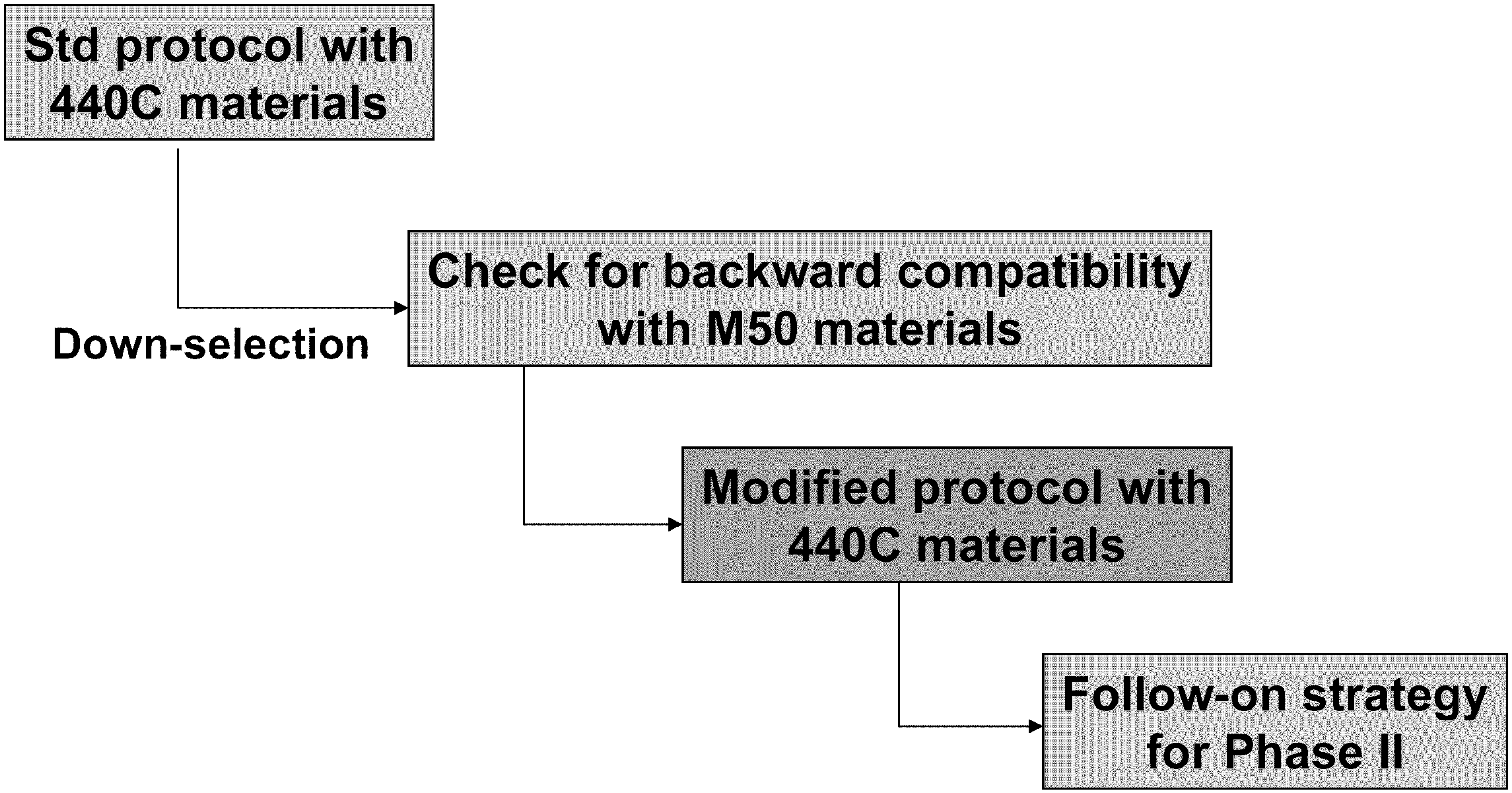
M50 disc specimen



440C disc specimen

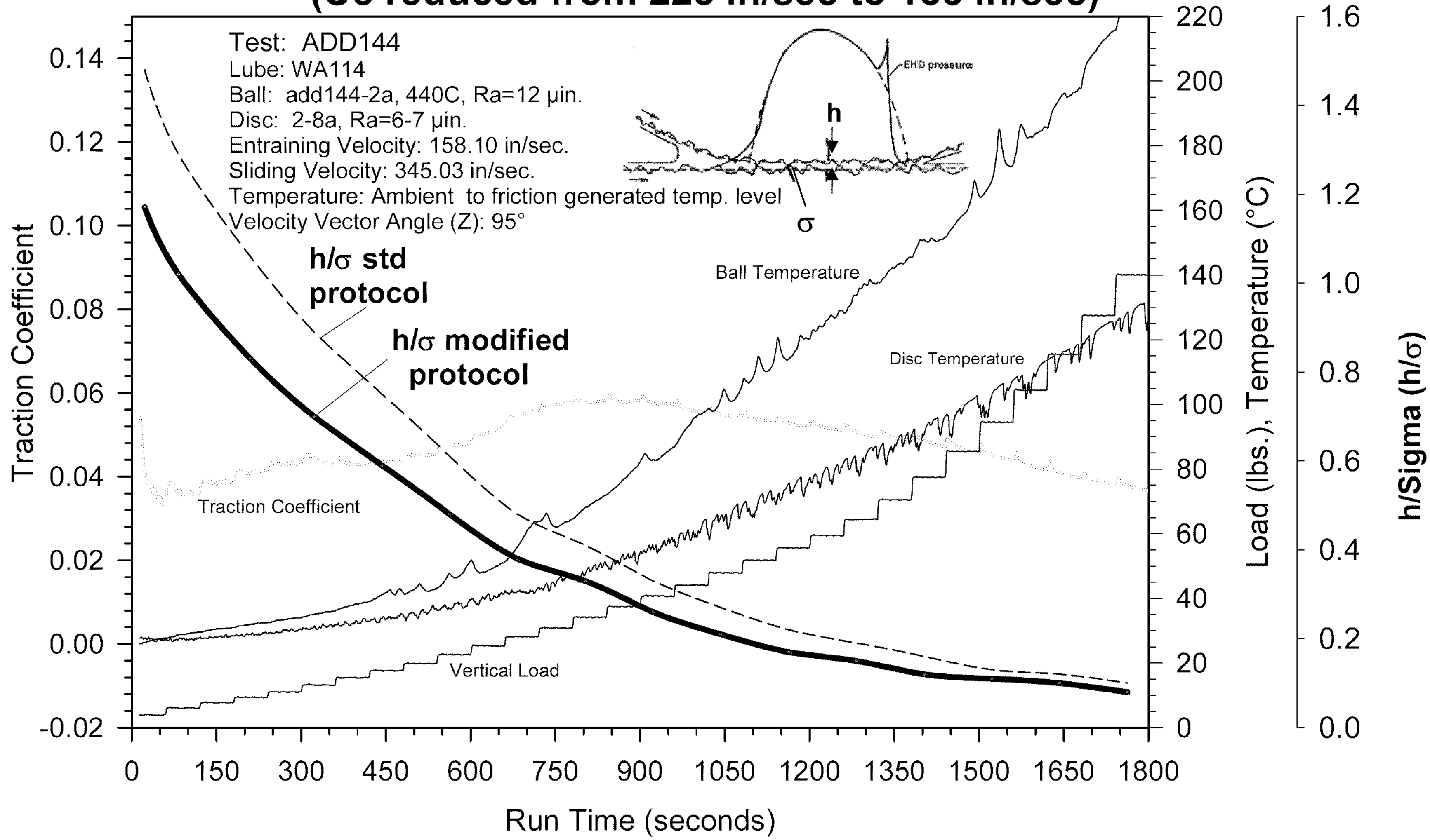
Oil: Formulation WA113

Screening Test Process

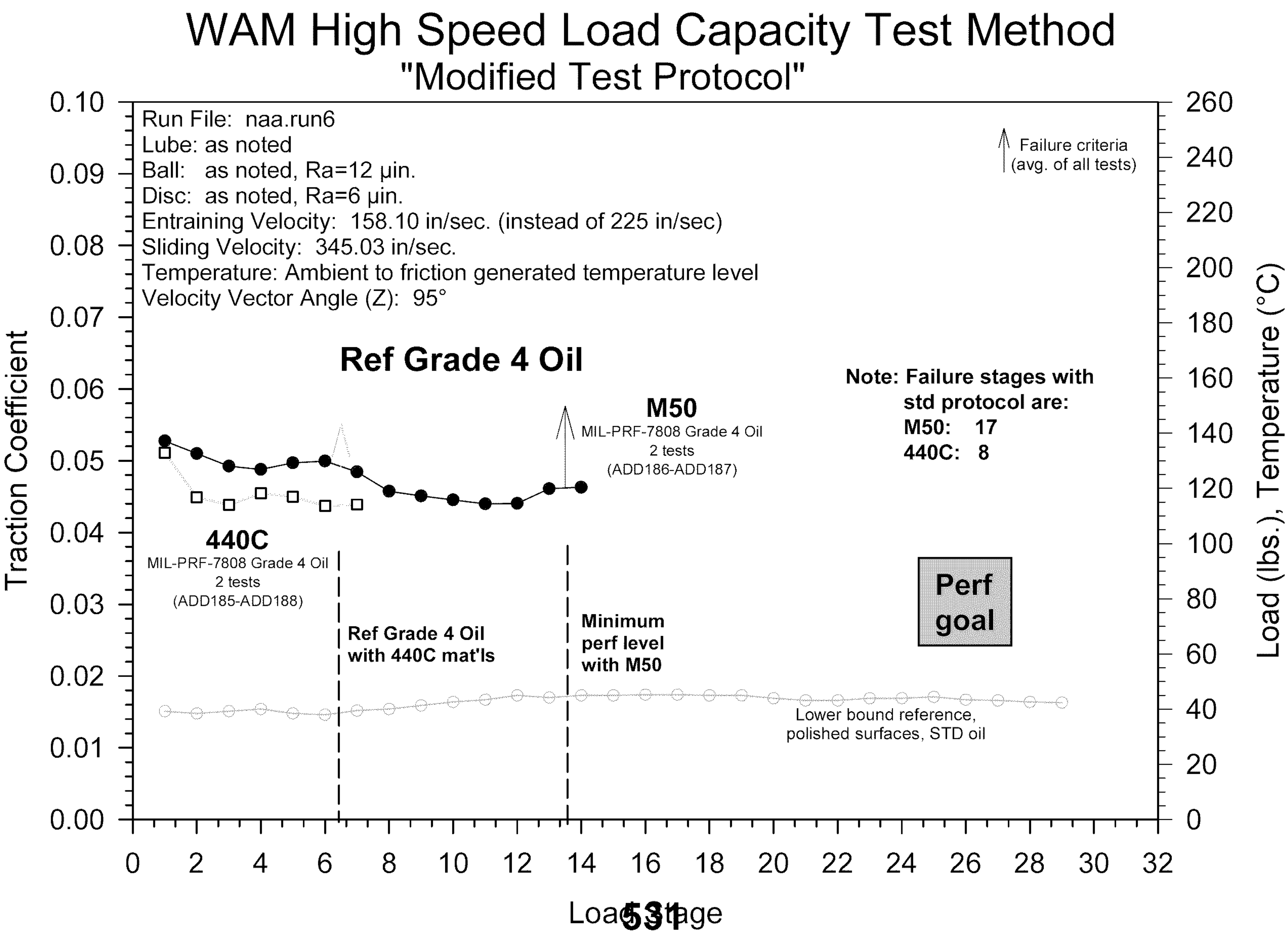


Screening Test with Modified Protocol

Modified protocol used for high load-carrying oils
(Ue reduced from 225 in/sec to 158 in/sec)



Reference Oil Tests with Modified Protocol



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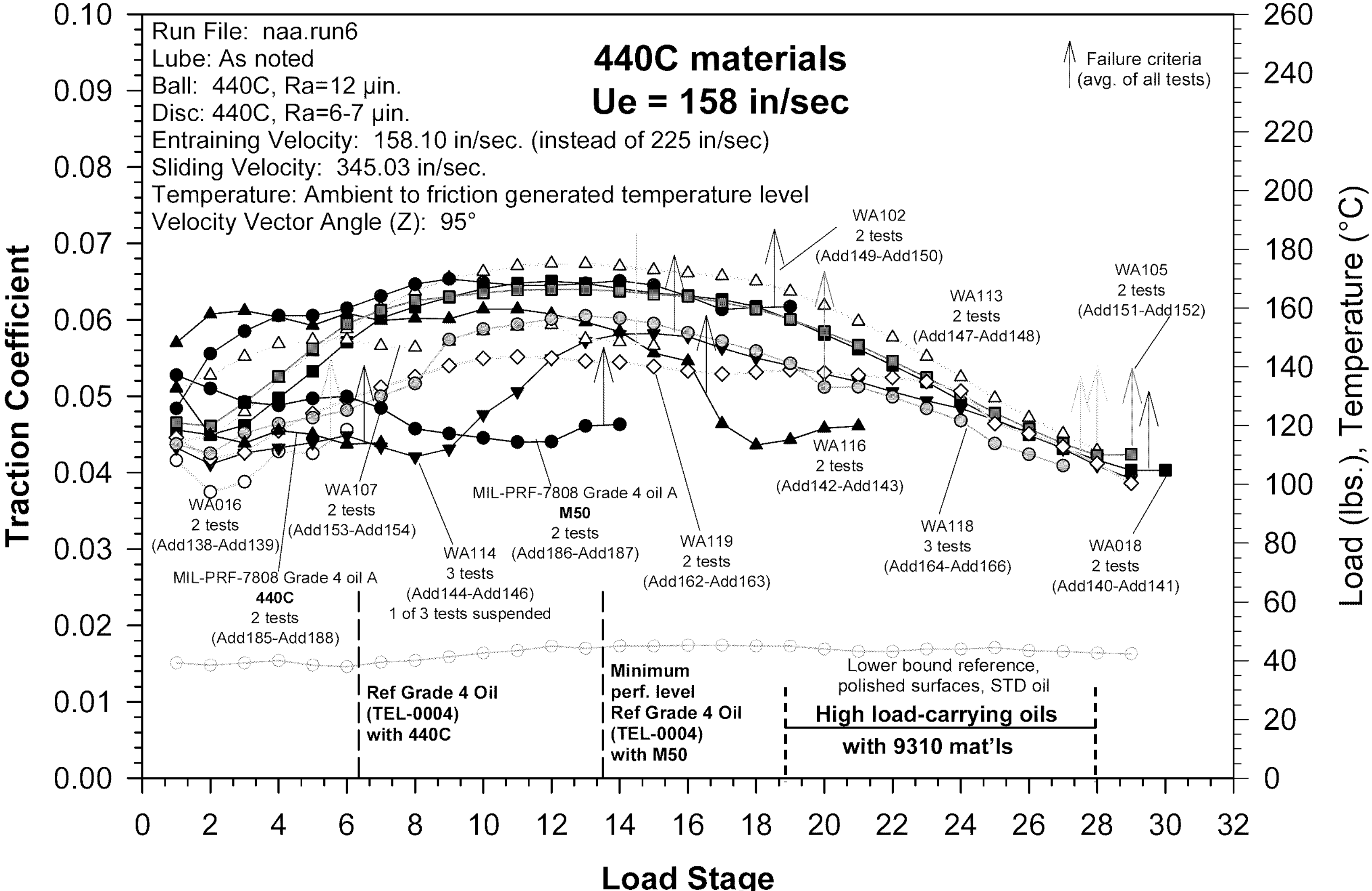
wamlcc/sbir-add/Modifiedtestprotocol/RM284A.jnb

Results with Modified Protocol

Some formulations are in same league as high load-carrying aviation gearbox oils, even with 440C materials!



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Summary of Phase I Results

Eleven additive formulations reach the lubricating performance goal for continuation into Phase II

All key suppliers have at least one formulation that substantially enhances boundary lubrication performance with 440C materials

Four additive formulations out-perform high load-carrying DOD-PRF-85734 oils – opportunity for improved gearbox performance and single oil for engine and gearbox!

Technical and business approach has motivated oil/additive suppliers; significant interest from OEMs and military oil approval authorities (AF & Navy)

SBIR Phase II Plans

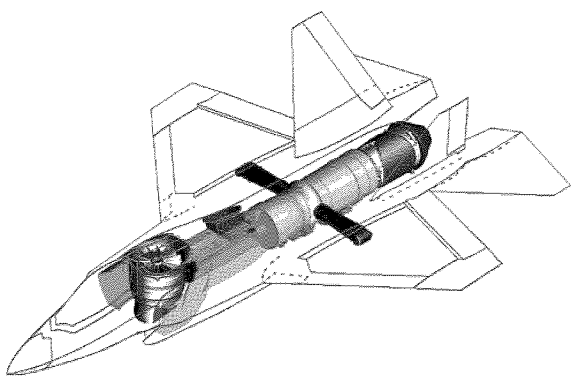
Task 1
Advanced base stocks for single viscosity grade

Task 2
Initial screening of eleven Phase I additive formulations for coking & tribology (with P675 mat'ls)

Screen 11 candidates from Phase I

Air BP (2)	Vanderbilt (1)
ExxonMobil (2)	Lubrizol (3)
Surf Res & Appl (2)	WA, Inc. (1)

Task 3
Down-selection, reformulation and comprehensive tribology, deposition & material compatibility testing



Task 4
40 mm P675 bearing tests
(2 candidates)
and
T63 engine test
with best candidate

HME 133 mm bearing test?

RR Lift fan or Navy gearbox demo?

JSF engine demo
(2007)

CONDITION MONITORING

Combining On-Site and On-Line Techniques For Improved Capabilities

Robert E. Kauffman
University of Dayton Research Institute

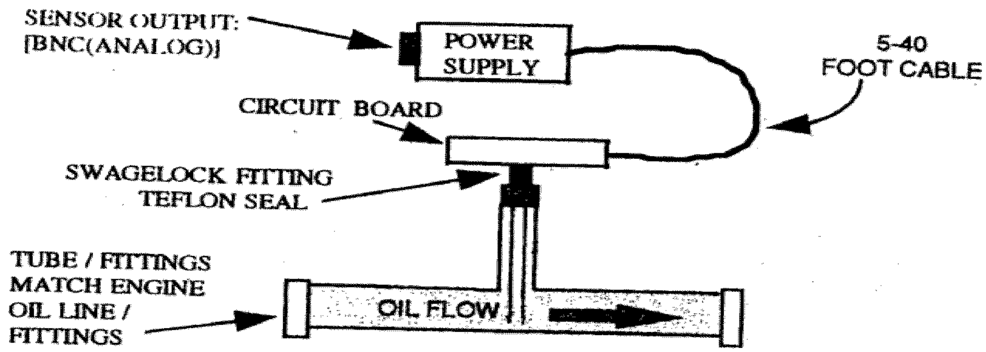
Oil Condition Monitoring (OCM) Sensors

- On-Site Antioxidant Depletion (RULER) to detect:
  - Accelerated Oxidation: C-130, Helicopters, Commercial APU's
  - Differentiate Oxidation & Hydrolysis: Forestry, Steam Turbines
  - Differentiate Oxidation & Thermal Breakdown: F16s "Black Oil"
  - Predict Accelerated Wear: Hydraulic pumps, HMMWVs, Greases
  - Incorrect Fluid Top-offs: Helicopters, APU's, Steam Turbine
- On-Line OCM sensors to detect:
  - Additive Depletion: Cooking oils, Diesel & Jet Engine Test Stands
  - Contaminant Build-up: Soot, Coolant and Fuel on Diesel Test Stand
  - Hot Spot/Fire: Laboratory tests, F-16 and Commercial "Black Oils"
  - Degradation by Contaminant: Coolant/Motor Oil in Jet Oil (Lab)

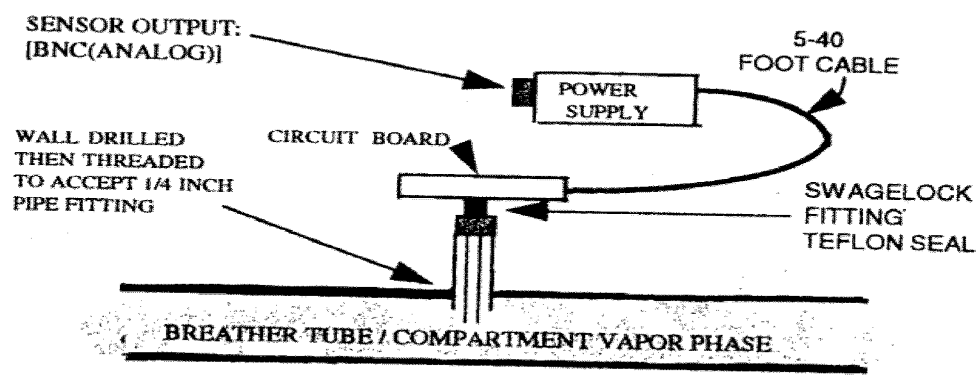
Joint Strike Fighter
Seeded Fault Engine Test

- Accelerated Oxidation Test - Oil cooler by-passed up to 80% to reach 232°C (450°F) at 9900 rpm
- RULER (On-site OCM) used to monitor antioxidant depletion
- Acid Number (AN) and COBRA (On-Site OCM) used to monitor oil degradation
- On-Line OCM (Conductivity) Sensors in liquid and vapor used to monitor oil degradation, fire in #5 bearing compartment, contamination

Simple, light-weight OCM sensors used for laboratory and JSF engine test stand evaluations : +/- 3V square wave, Ni wire pair, nA response → 0 – 5V output



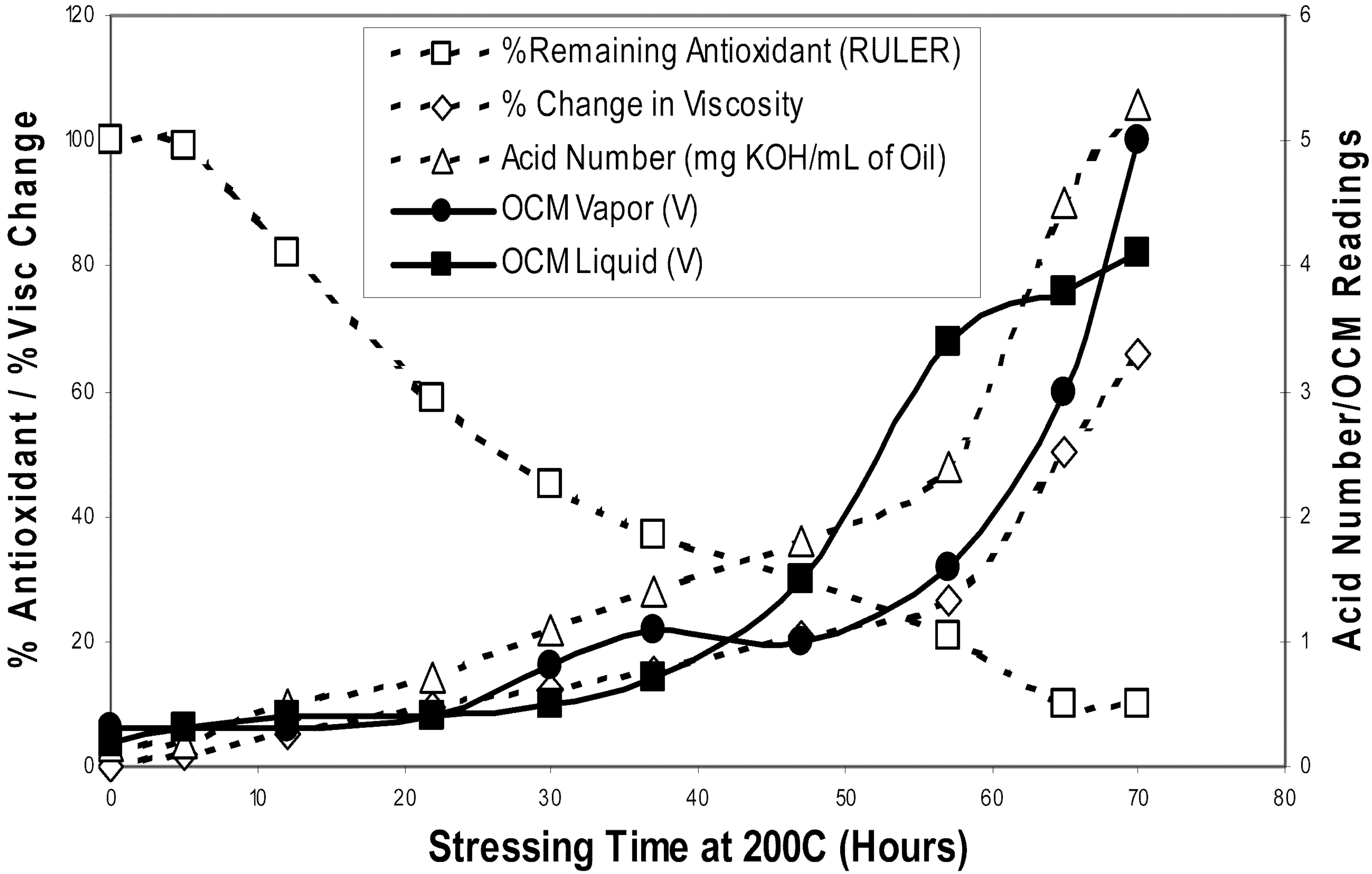
LIQUID SENSOR CONFIGURATON

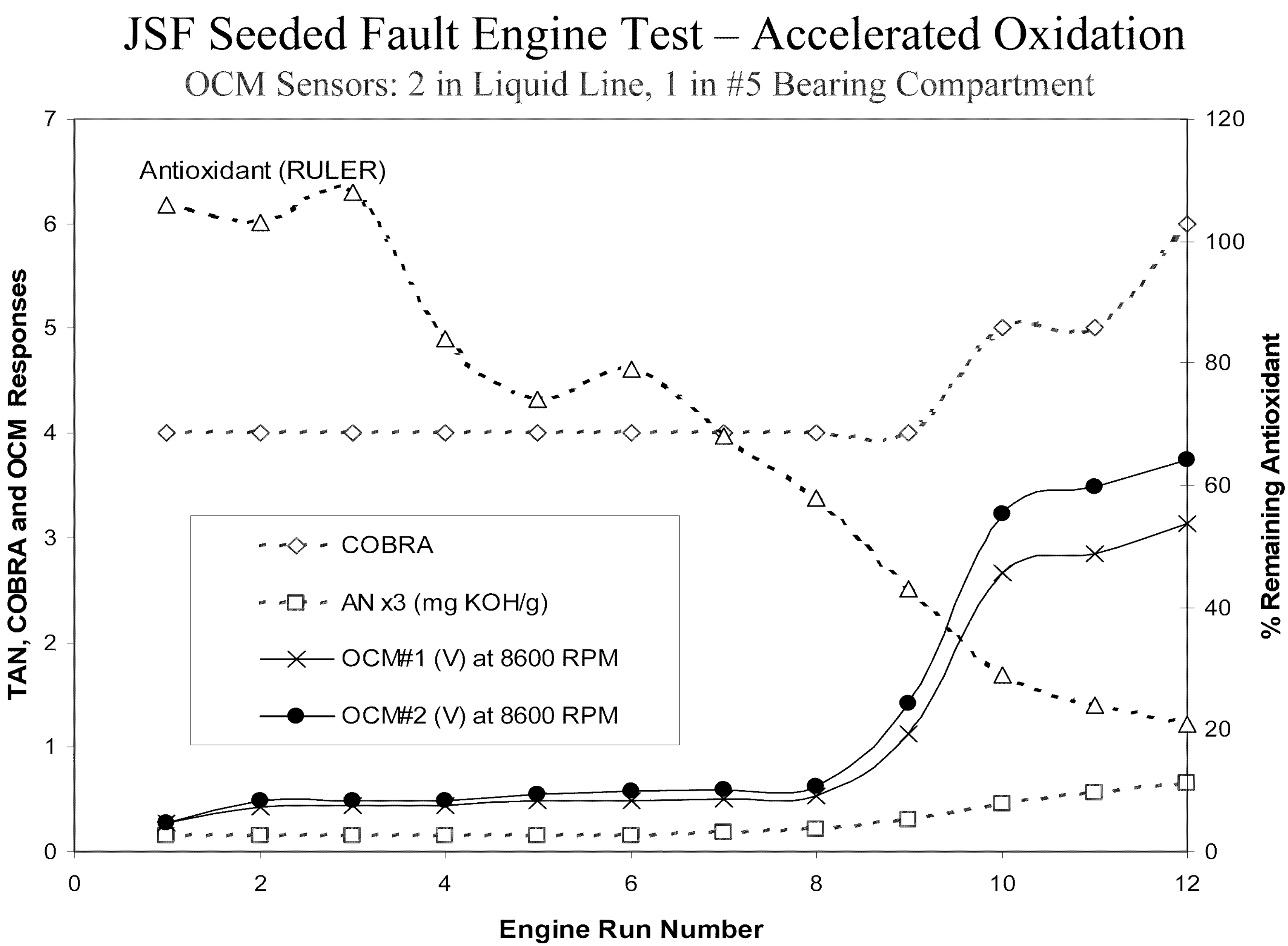


VAPOR SENSOR CONFIGURATION

Laboratory Oxidation Test – Glass Flask – HTS Oil

OCM Sensors: Liquid and at Open Top of Flask (Vapor)

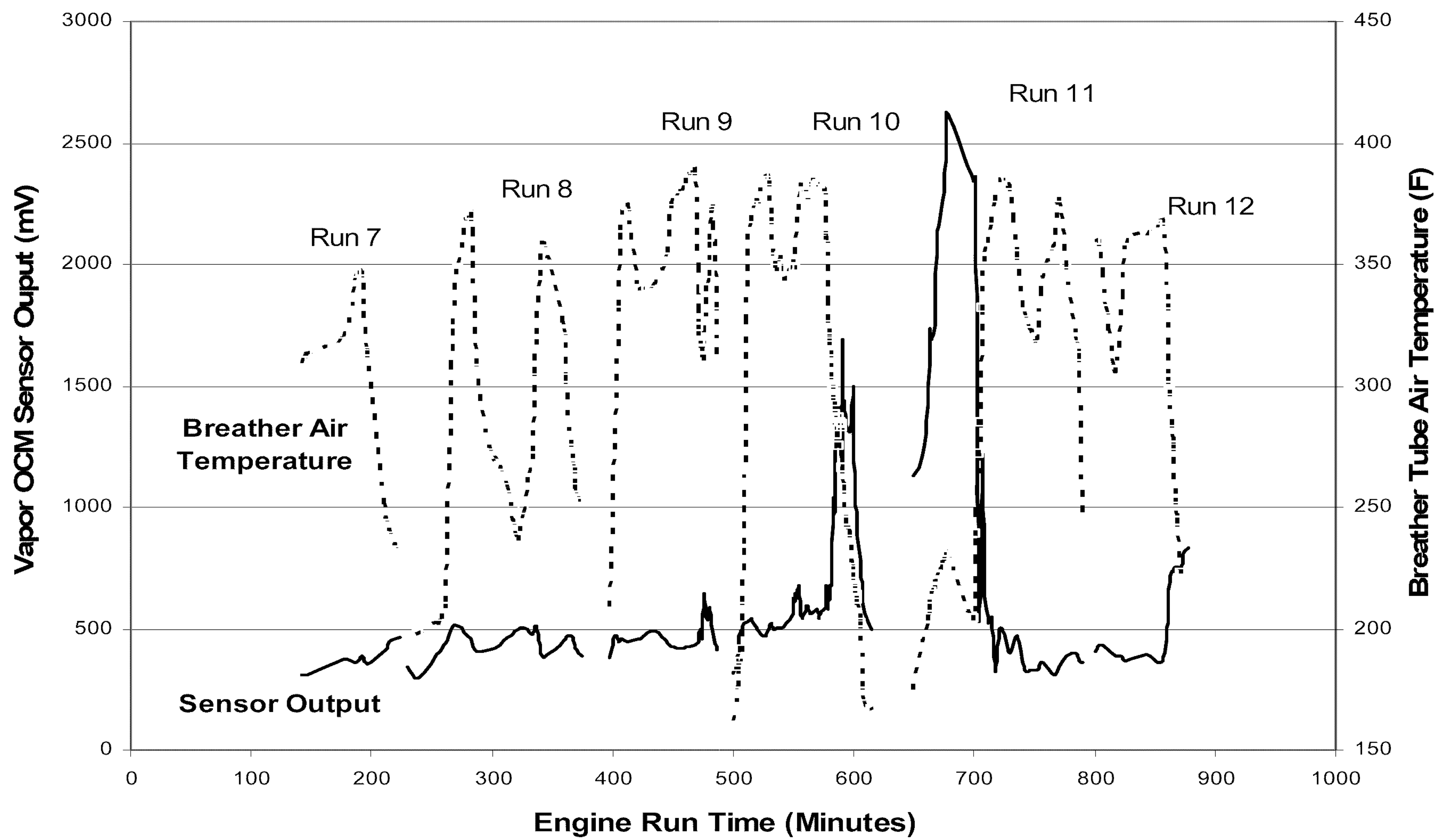




JSF Seeded Fault Engine Test – Accelerated Oxidation
OCM Sensors: 2 in Liquid Line, 1 in #5 Bearing Compartment
Antioxidant (RULER)
COBRA
AN x3 (mg KOH/g)
OCM#1 (V) at 8600 RPM
OCM#2 (V) at 8600 RPM
TAN, COBRA and OCM Responses
% Remaining Antioxidant
Engine Run Number
0
1
2
3
4
5
6
7
8
10
12
20
40
60
80
100
120

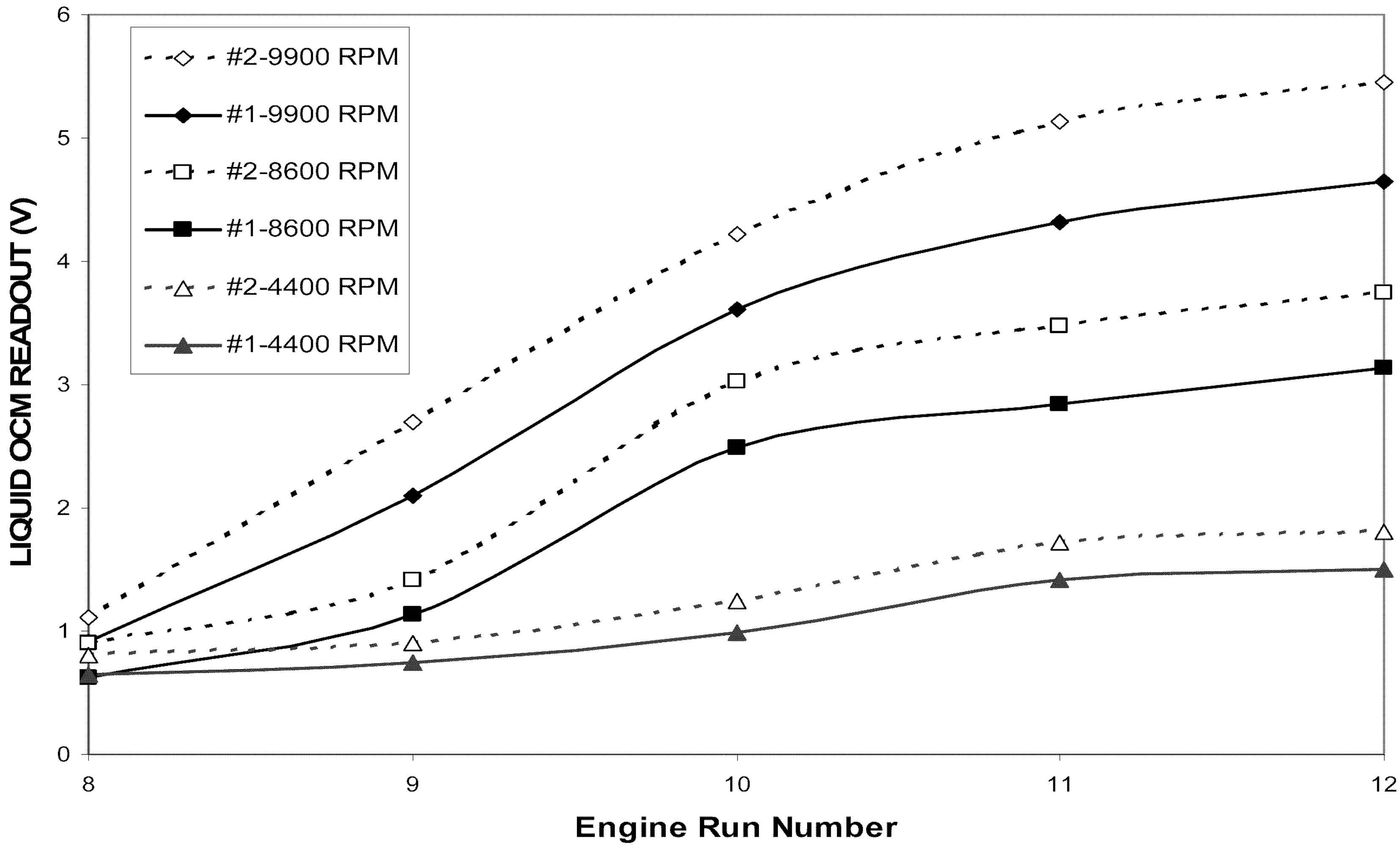
JSF Seeded Fault Engine Test – Accelerated Oxidation

Vapor OCM Sensors: 2 in Breather Tube, 1 in Scavenge Line



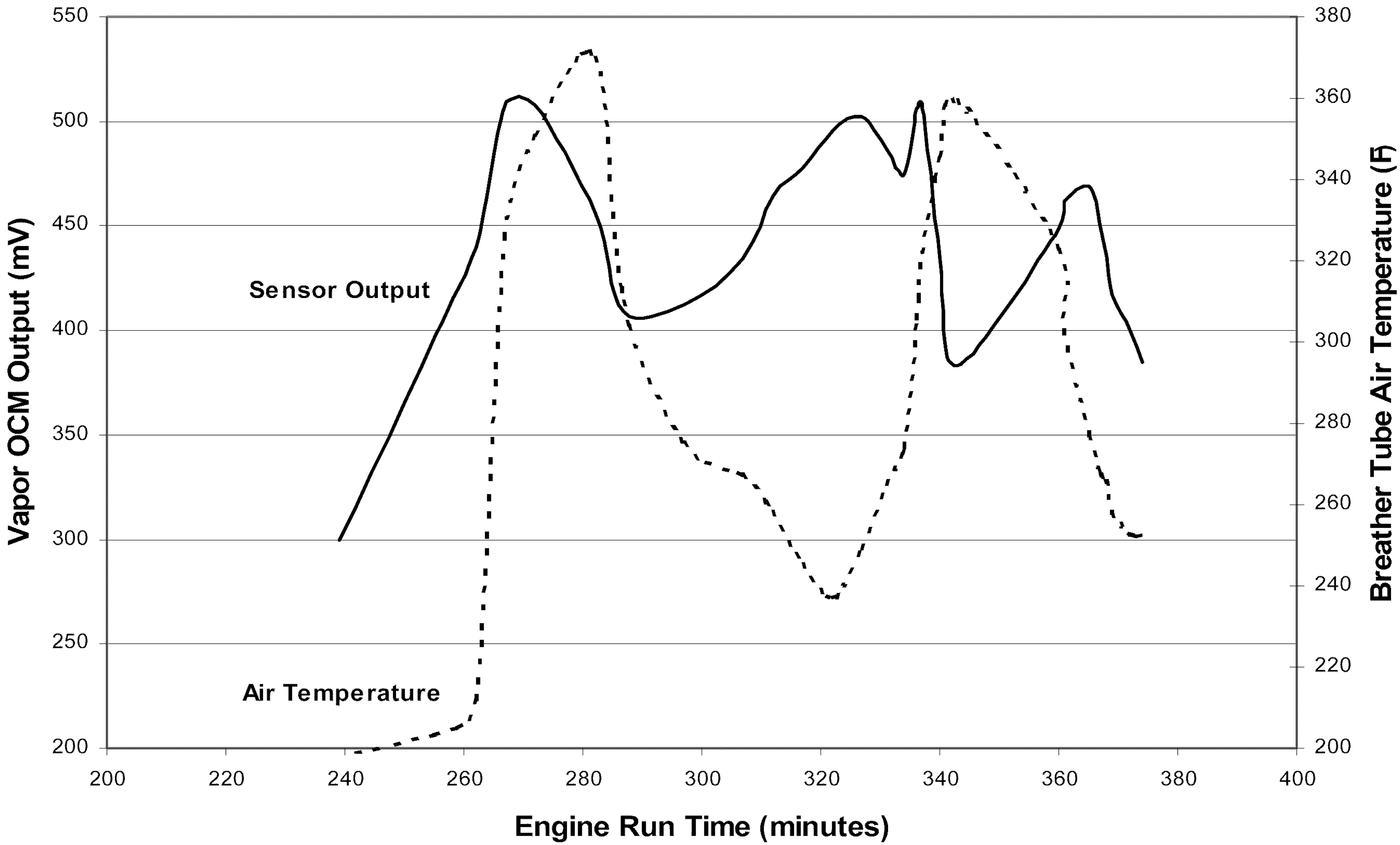
JSF Seeded Fault Engine Test – Accelerated Oxidation

Effects of Temperature (200 – 450°F) & Oxidation on Liquid OCM Readings



JSF Seeded Fault Engine Test – Accelerated Oxidation

Effects of Temperature & Oxidation on Vapor OCM Readings for Engine Run #8



CONCLUSIONS

- Combining On-Site (RULER) and On-Line (Conductivity) OCM techniques greatly improves capabilities to detect abnormal operating conditions prior to component damage
- On-line OCM sensors:
  - Can be placed in liquid or vapor
  - Improved capabilities at higher/different temperatures
  - Detect wide range of degradation mechanisms
  - Placed on HMMWV diesel engine dipstick (US Army work)
    - Soot, Oxidation, Coolant, Fuel
    - Oil level, Temperature
  - Being commercialized by different licensees for different applications

Aging Aircraft Systems Squadron

Rapidly delivering war-winning capability

Hydraulic Fluid Purification

17 Jun 2004

Carolyn Tucker
ASC/AAAT
DSN Phone # 785-7210 X3622
Email address:
Carolyn.Tucker@wpafb.af.mil

U.S. AIR FORCE

Keep'em flying & Keep'em relevant

Purification Overview

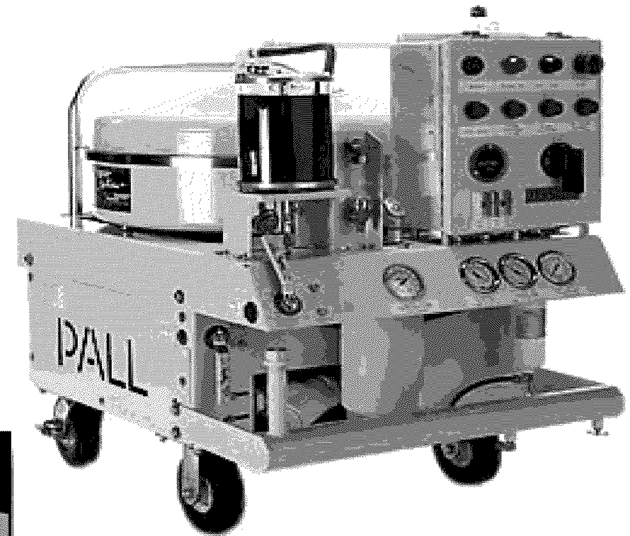
Rapidly delivering war-winning capability

- History
- Qualifications
  - Phase I
  - Phase II
  - Phase III
- Purification Equipment
  - Malabar
  - Pall

HFP History

Rapidly delivering war-winning capability

- Army
- Navy
- Air Force



CH-47 Hydraulic Fluid Savings

- CH-47 goes through phase every 18 months
- 480 CH-47s in the Army
- 480 X 0.667 = 307 = Number of aircraft in phase annually
- Prior to purification / 53 gals hydraulic fluid required per aircraft
- After purification / 1 gal hydraulic fluid required per aircraft
- 52 gallons saved per aircraft
- 307 X 52 = 15,964 Gals x $10 Avg = $159,640.00 Savings per year

NAVY HFP

Rapidly delivering war-winning capability

- 13 years of HFP on Aircraft (F-14 / F-18)
  - 520 Aircraft based on carriers
  - 800 gallons of Hyd fluid used total in 2002
  - <2 gal per year per aircraft used (very low)
- 37 years of HFP on Submarines
  - Fluid disposal was an issue
  - Limited space to carry new and used fluid

USAF Phase I (Apr 00 – Jun 03)

Rapidly delivering war-winning capability

- Sought to validate the process of purifying hydraulic fluid.
- Research existing purification programs in use by other services for procedure and performance data
- Rewrite current 42B2-1-3 Technical Data to allow Hydraulic Fluid Purification
- Find ways to reduce yearly hydraulic fluid waste stream

USAF Phase II (Mar 04 – Jun 04)

Rapidly delivering war-winning capability

- Conduct Operational Utility Evaluation
  - Use Mules from Kirtland AFB
    - 58th SOW
    - 150th FW
- HFP processes further defined & documented
- Assess suitability/effectiveness of Pall Purifier
- Initiate Tech Data procedure incorporation

USAF Phase III (Jan 05-Sep 10)

Rapidly delivering war-winning capability

- Develop Hydraulic Fluid standards
  - 13 Different Aircraft
    - 53 Bases, 570 Samples
  - Aerospace Ground Equipment
    - 54 Bases, 213 Mule Samples
- Field Implementation
  - Introductory MDS
    - C-17, F-22, F-16, B-1
  - Full Field implementation
- AFRL, ASC/AA, MAJCOMs & ALC Involvement

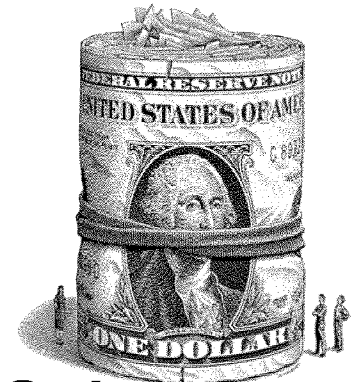
WHY HFP?

- Manhours Required to Drain and Flush
  - Contaminated Systems Require Drain and Flush Three Times to Purge System
- Large Mobility/Supply Footprint
- Large Hydraulic Fluid Waste Stream
  - Pollution Prevention for Environment
  - High Cost of Waste Disposal
- Significant Cost Savings

HFP Return on Investment

Rapidly delivering war-winning capability

- Savings in new fluid procurement (AF)/ ALL FLUIDS
  - Estimated 0.9M gal X $10/Gal X .90 = $8.1M
- Savings in used fluid disposal cost
  - Estimated 0.8M gal X $1.50/gal = $1.2M
- Total savings = $9.3M Annually

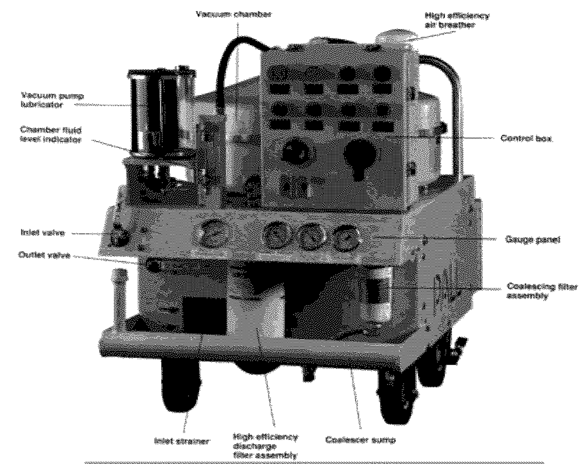


- Savings in fluid procurement (AF)/ Synthetic Only
  - Estimated 0.520M gal X $10/Gal X .90 = $4.7M
- Savings in used fluid disposal cost
  - Estimated 0.470M gal X $1.50/gal = $0.7M
- Total savings = $5.4M Annually
- 5 Year ROI ratio = 37:1 (5.4 X 5 = 27M/730K)

Hydraulic Fluid Purification

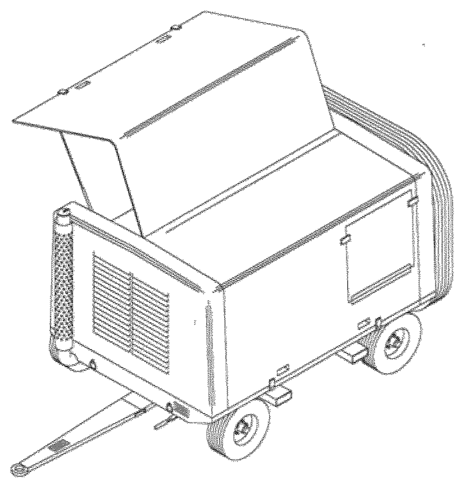
Rapidly delivering war-winning capability

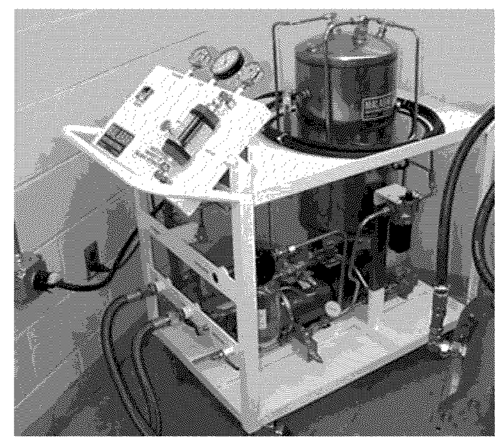
- **How the purifiers work:**
  - Create large fluid surface area using a spinning disk or by misting
  - Partial vacuum to remove volatiles
  - High efficiency fine filter
  - Some use absorption/adsorption to remove water



Pall Portable Purifier

- **Effective in removing**
  - Particulate Contamination
  - Moisture
  - Solvents
  - Air (Entrained and Dissolved)
    - Spongy flight controls
    - Pump cavitation
    - Fluid over-temp





Malabar Ground Test Stand with Built-in Purifier

- **Portable and built-in configurations**

Malabar Purification Unit

Rapidly delivering war-winning capability

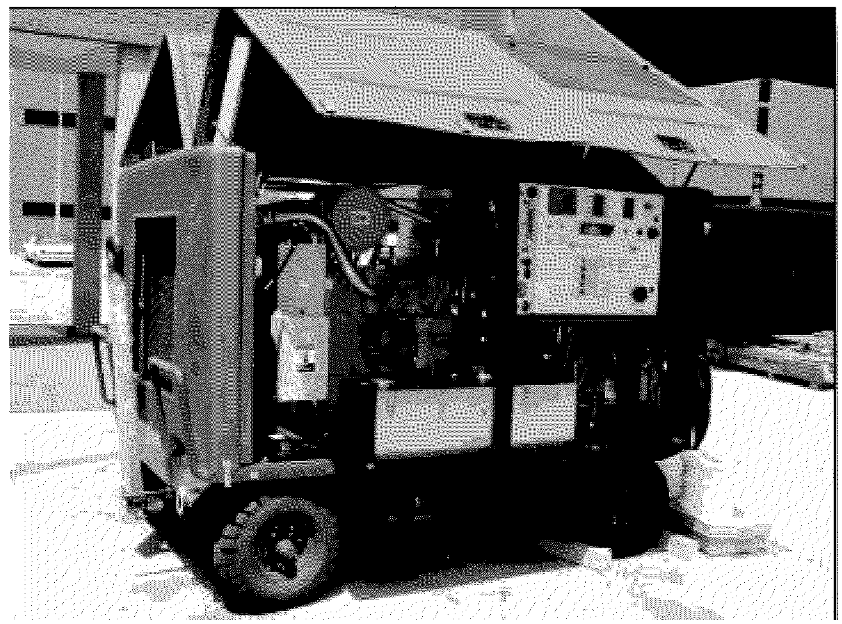
Type I, HTS 3/D, Part No. 26001, NSN 4920-01-380-7460, 3 System, Diesel Engine Driven.

Type II, HTS 3/E, Part No. 26003, NSN 4920-01-380-4744, 3 System, Electric Motor Driven.

Type III, HTS 2/D, Part No. 26002, NSN 4920-01-434-1081, 2 System, Diesel Engine Driven.

Type IV, HTS 2/E, Part No. 26004, NSN 4920-01-434-3206, 2 System, Electric Motor Driven.

- Units on contract with WR-ALC/LESG
- OT&E in progress



Pall Hydraulic Fluid Purifier

Rapidly delivering war-winning capability

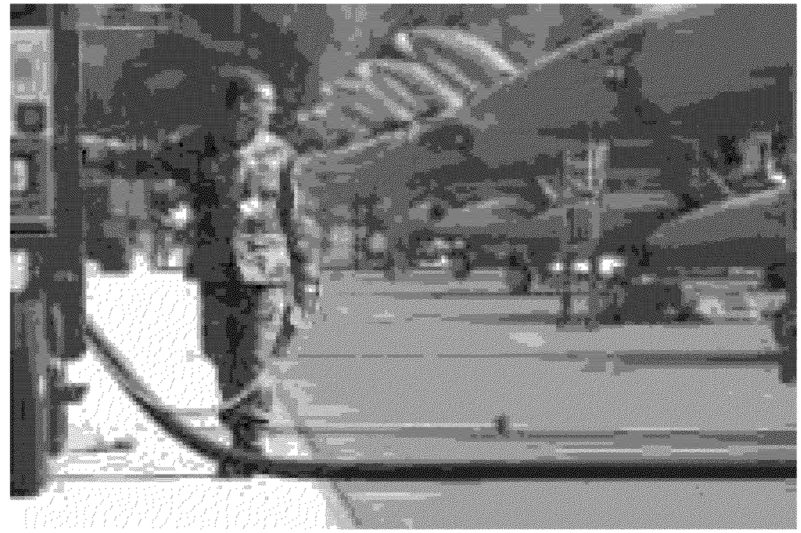
- **Purification**
  - -- Particulate Reduction
- **Water Reduction**
  - -- Free & Dissolved
  - -- Air Reduction
  - -- Solvent Removal
  - -- Synergistic Effects
- **Filtration**
  - -- Particulate Reduction

4330-01-470-1855

P/N PE01078-12-H-83

Purification Conclusion

Rapidly delivering war-winning capability



- Qualifications
  - -- Phase I (complete)
  - -- Phase II (In Work)
  - -- Phase III (In Work)

    Implementation Support
- Purification Equipment
  - -- Malabar
  - -- Pall
- Funding

Hydraulic Fluid Purification Background

Ed Snyder, Lois Gschwender, Shashi Sharma
Air Force Research Laboratory
Wright-Patterson AFB, OH

HFP - Background

- Outline
  - Cleaning Ability Demos
  - Aircraft Interface Demos
  - Hydraulic Test Stand Demos
  - Does HFP Degrade Fluid Properties
    - Pump Test – MIL-PRF-5606
    - Pump Test - MIL-PRF-83282
      - Pall Purifier
      - Malabar Purifier
  - T.O. 42B2-3-1 Revision
  - Malabar Test Stand Qualification Test
  - Recommendations

HFP – Cleaning Ability Demos

- All tests done to date with Pall Fluid Purifiers
  - 1988 – Hill AFB purified a 10 gallon drum of MIL-PRF-5606
  - 1995 – Tyndal AFB purified a 22 gallon drum of MIL-PRF-83282
  - 1998 – McChord AFB purified:
    - 55 gallon drum of MIL-PRF-5606
    - 55 gallon drum of MIL-PRF-83282
    - 55 gallon drum of MIL-PRF-87257
- All tests demonstrated ability of purifiers to remove particulate, water and solvent contamination
- 2003 – WPAFB demonstrated Malabar purifier in new test stand removed particulate, water and solvent contamination

HFP – Aircraft Interface Demos

- All tests conducted with Pall Fluid Purifier
  - 1989 – Tinker AFB – B-52 MIL-PRF-5606
  - 1989 - Tinker AFB – B-1B MIL-PRF-5606
  - 1990 - NASA, Houston TX – T-38* MIL-PRF-5606
  - 1992 - Moody AFB – F-16 MIL-PRF-83282
  - 1993 - Travis AFB - C-5 MIL-PRF-83282
  - 1998 - McChord AFB– C-141 MIL-PRF-83282
  - 2000 - Beale AFB – U-2 MIL-PRF-87257

- All tests except * were successful

HFP – Hydraulic Test Stand Demos

- All Tests Conducted with Pall Purifier
  - 1992 Moody AFB – PHTS MIL-PRF-83282
  - 1993 Travis AFB – PHTS MIL-PRF-83282
  - 1995 North Island NAS – PHTS MIL-PRF-83282
  - 1998 McChord AFB – PHTS – MIL-PRF-83282
  - 1998 McChord AFB – HTS – MIL-PRF-83282
- All Tests Were Successful

Does HFP Degrade Fluid Properties?

- AFRL/MLBT responsible for hydraulic fluid quality for the Air Force
  - Prepare MIL-Specs for hydraulic fluids
  - Qualify Product for those specs
  - Trouble shoot suspected hydraulic fluid related problems in the field
- Before we could recommend hydraulic fluid purification for field use, needed to know HFP would not degrade hydraulic fluid performance properties

Does HFP Degrade Fluid Properties?

- In conjunction with SPOs and potential users MLBT developed a test protocol for extended hydraulic pump testing with repeatedly purified hydraulic fluid to answer this question
- Hydraulic pump most demanding component for fluid properties.
  - Rotating, sliding, oscillating metal on metal contacts
  - Highest temperature
  - Sensitive to foaming
- Shashi Sharma will be presenting that data in the next presentation

Hydraulic Fluid Purification

- Summary
  - Pall purifier tested with both MIL-PRF-5606 and MIL-PRF-83282
    - No degradation of fluid performance resulting from purification
  - Malabar purifier tested with MIL-PRF-83282
    - No degradation of fluid performance resulting from purification
  - At the conclusion of pump tests, both 5606 and 83282 met new fluid properties except for 5606 losing viscosity due to shearing in the pump test stand
    - Shows that MIL-PRF-83282 does not "Wear out" and can be used for long periods of time in aircraft hydraulic systems

T.O. 42B2-3-1 Change

Excerpt from T.O.

Purification is approved only for MIL-PRF-83282 and MIL-PRF-87257 hydraulic fluids. No other fluids have been approved for purification.

c. Use of purified hydraulic fluid is permitted if the following requirements have been met:

1. The applicable aircraft SPO has approved the use of purified hydraulic fluid.
2. Only approved units are used to accomplish purification of the fluid. Units currently approved for use are:

(a) NSN 4920-01-380-7460
(b) NSN 4920-01-380-4744
(c) NSN 4920-01-434-1081
(d) NSN 4920-01-434-3206
(e) NSN 4330-01-470-1855

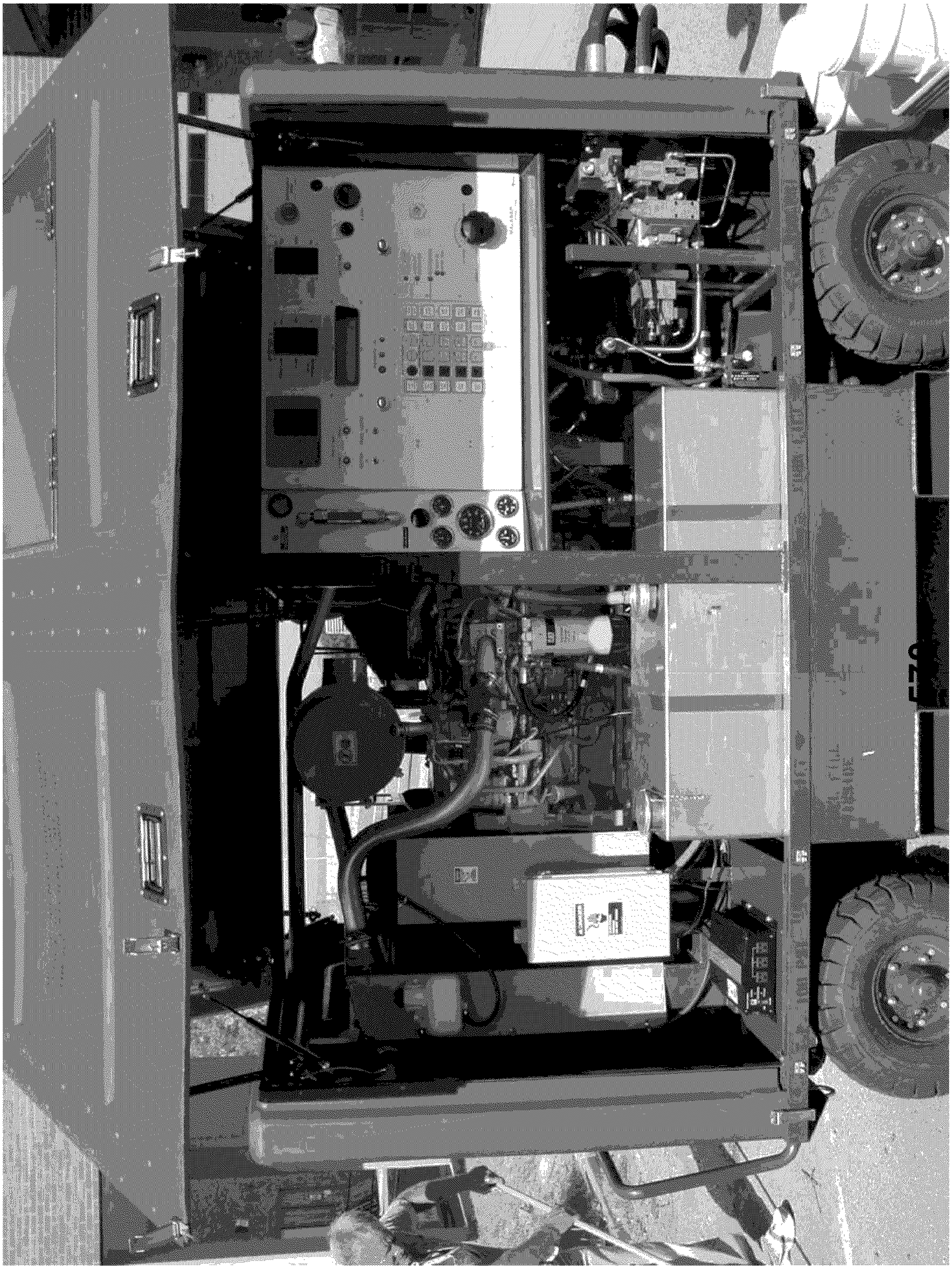
Any deviation from this list must be approved by AFRL/MLBT, Wright Patterson AFB OH. AFRL/MLBT will notify Det 3, WR-ALC/AFTT of any changes or additions to this list.

d. Purification units shall only be attached to portable hydraulic test stands or service carts. Purification units can be attached directly to the aircraft only with aircraft SPO approval.

Malabar Test Stand

Contamination Removal Tests

Malabar Test Stand



Hydraulic Fluid Purification Requirements

- Particulate: From NAS 1638 Class 11 to Class 5
- Water: From 600 ppm to 150 ppm
- Chlorinated Solvent: 300 ppm to 50 ppm
- Dissolved Air: 12% to 7% (8%)

All of these requirements must be met within 8 hours of purification on 40 gallons of MIL-PRF-83282 hydraulic fluid

Contamination Removal from MIL-PRF-83282 by Malabar Test Stand

(Fluid Contaminated Prior to Test with Particulate, Water and Chlorinated Solvent)

TEST	WATER (PPM)		CHLORINE ppm		% AIR	PARTICULATE NAS 1638		
HOURS	METER	KF	RUN 1	RUN2	by GC	PT12	PT13	OUTLET
0	584	455	293	293	12	11	a	a
1	342	334	226	221	8	5	5	6
2	245	237	192	184	8	4	5	6
3	169	171	146	145	8	4	4	5
4	120	117	123	120	7	5	4	6
5	89	90	105	101	7	4	3	6
6	65	69	76	75	7	4	4	4
7	52	44	69	63	7	2	2	3
8	40	46	60	54	7	2	4	3

At conclusion of Malabar Test Stand cleaning effectiveness tests, used MIL-PRF-83282 still met new fluid specification requirements for:

- Viscosity
- Stability
- Lubricity
- Foaming

This assures us that not only does the purifier not adversely affect fluid properties, but the the fluid is durable enough for long term re-use

Malabar Test Stand Test Results

Malabar Test Stand meets requirements for cleaning hydraulic fluid

- Particulate: NAS 1638 Class 11 to ≤ 5
- Water: 600 ppm to ≤ 150 ppm
- Chlorine: 300 ppm to ≤ 50 ppm
- Air: 12% to $\leq 8\%$

Requirements were met by successfully removing contaminants from 40 gallons of MIL-PRF-83282 in eight hours

Recommendations

- Based on all the previous successful testing of the Pall and Malabar Hydraulic Fluid Purifiers
  - **Limited Field Evaluation is in order to get actual measurements of**
    - **Reduction in waste stream by implementing HFP**
    - **Increase in maintenance workload**
    - **Improvement in component life**
    - **Improvement in hydraulic system performance**
  - **This is the reason we are conducting a Phase III activity – volunteers are needed to participate**

Hydraulic Fluid Purification (HFP) AFOTEC Phase II Status

As of 28 May 2004

TSgt Christopher Brooks

Kirtland AFB NM

All data subject to final analysis after completion of assessment

HFP Phase II Assessment

- Assessment of integrated PPFP/PHTS configuration
  - 58th SOW and 150th FW, Kirtland AFB NM
- Equipment located in/near 58th and 150th AGE shops
- Purified for 4 or 8 hours depending on condition
  - Serviceable fluid purified for 4 hours
  - Unserviceable fluid purified for 8 hours
    - Condition established by visual inspection
  - Baseline purification time vs contamination levels
- Samples taken at 1-hour intervals
  - Analysis of particulate, water content, and fluid properties

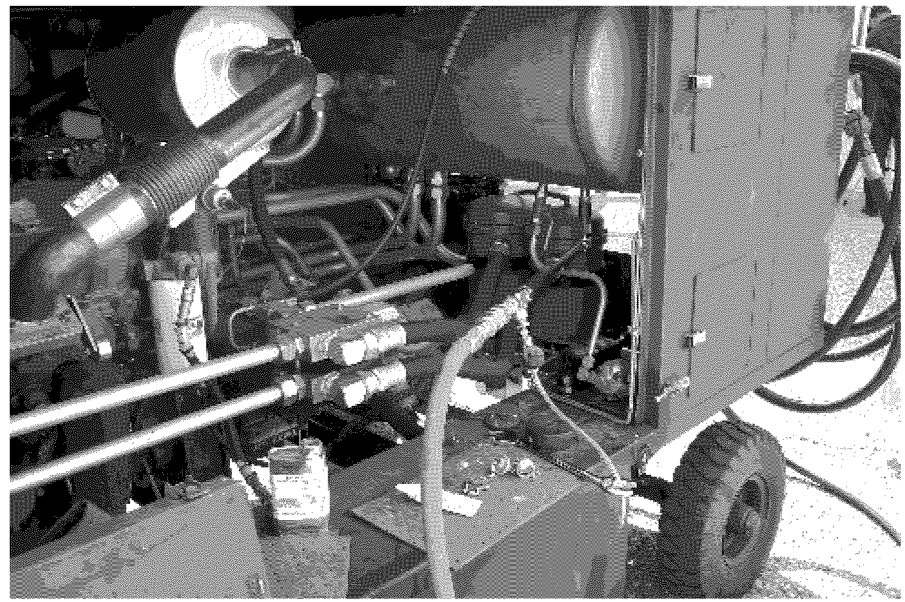
HFP Phase II Assessment Status

As of 28 May 2004

- Six of eight mules purified using PPFP
- Twelve warfighters received PPFP training
  - Set up, integration, operation, user maintenance
- Waste stream study completed for 58 SOW and 150 FW
  - Provides baseline for potential waste reduction
- Dates for final mules TBD -- operational requirements

PPFP/PHTS Integration

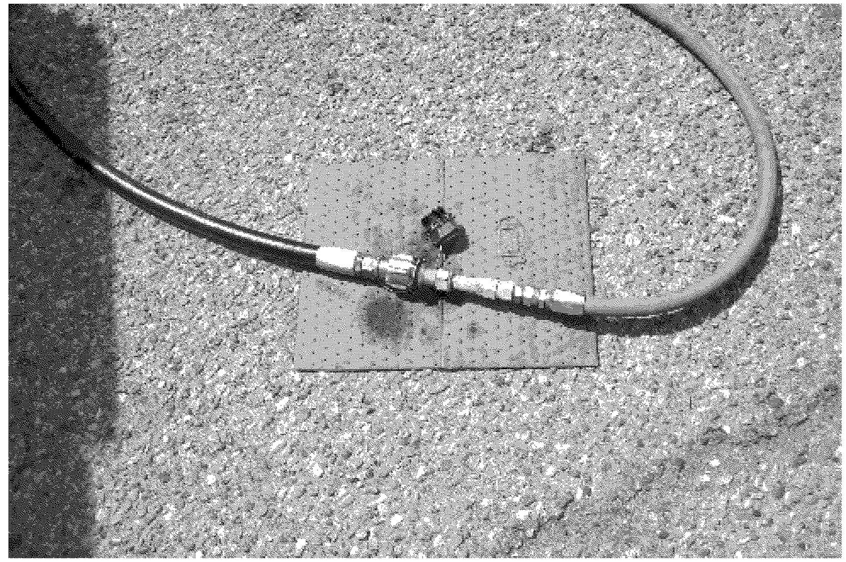
- PPFP input connected to reservoir drain
- PPFP output connected to one return line
- Sample valve/flow meter added for assessment
  - not envisioned operationally



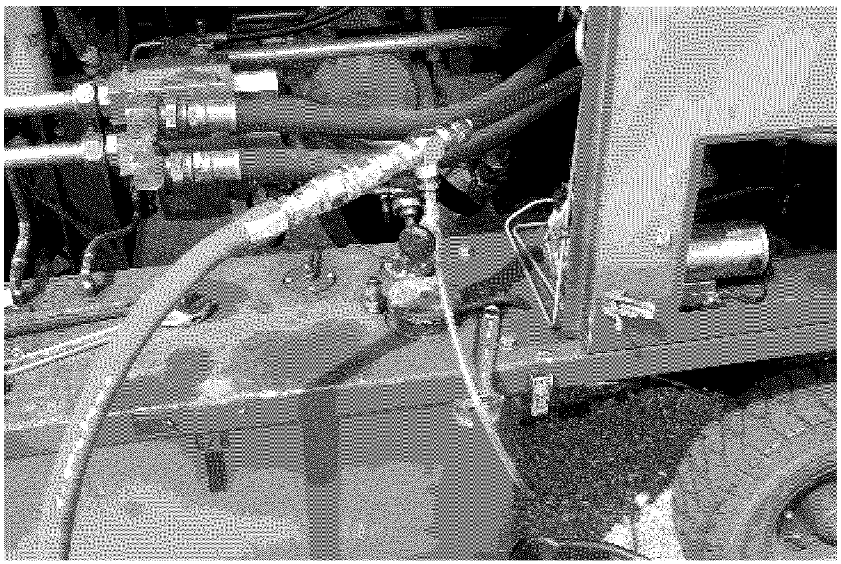
Reservoir Drain Valve Connection:
Fluid is drawn from mule reservoir into the PPFP.

PPFP/PHTS Integration

- **Quick disconnect hose connections used to avoid leaks and spills.**
- **Local manufactured adapter connected PPFP output hose to mule return line**



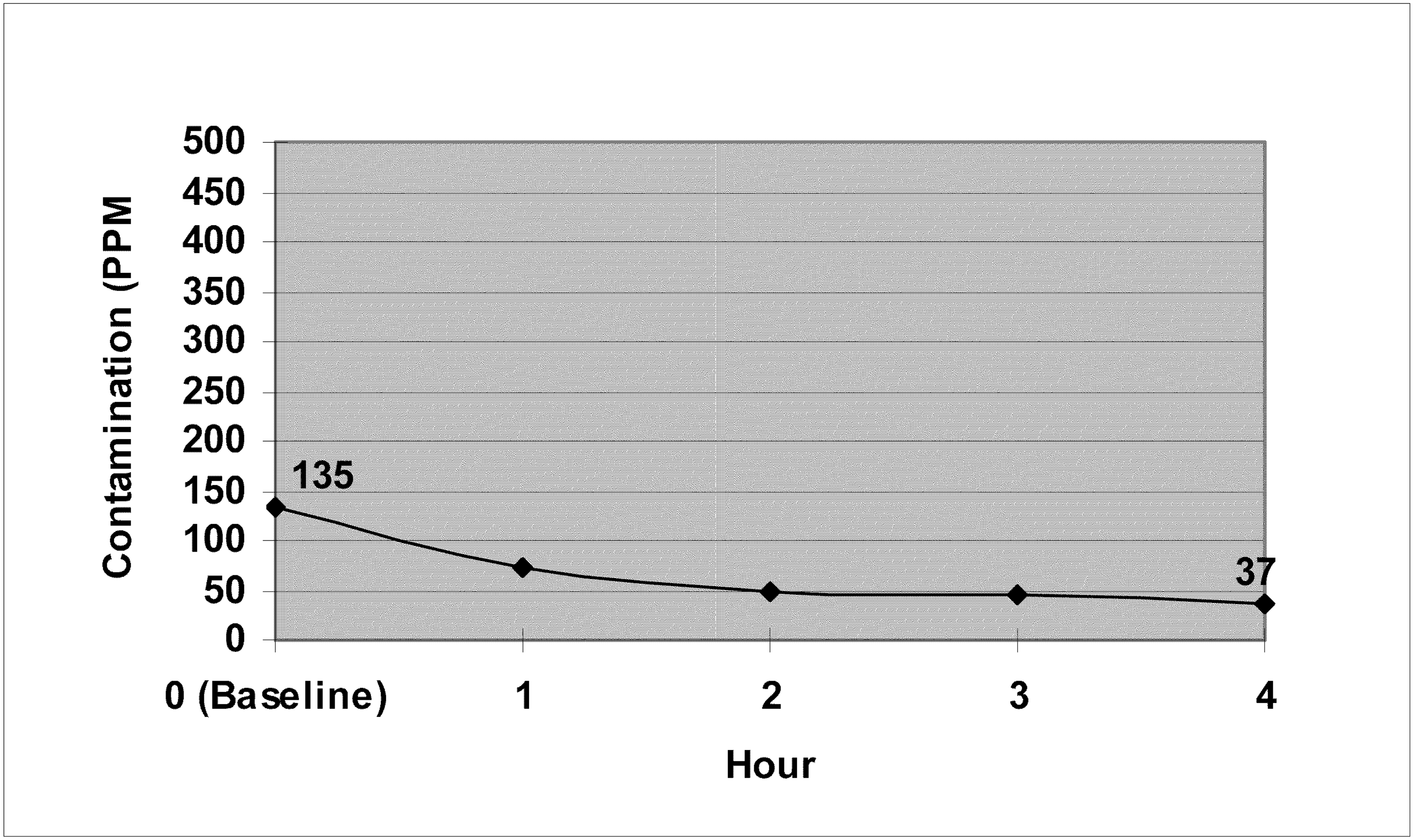
PPFP to Mule Hose Interface: ¾" JIC PPFP output hose to 1 ¼" quick disconnect return line.



Sampling Valve Assembly: Fluid samples were taken from this ¼" ball valve.

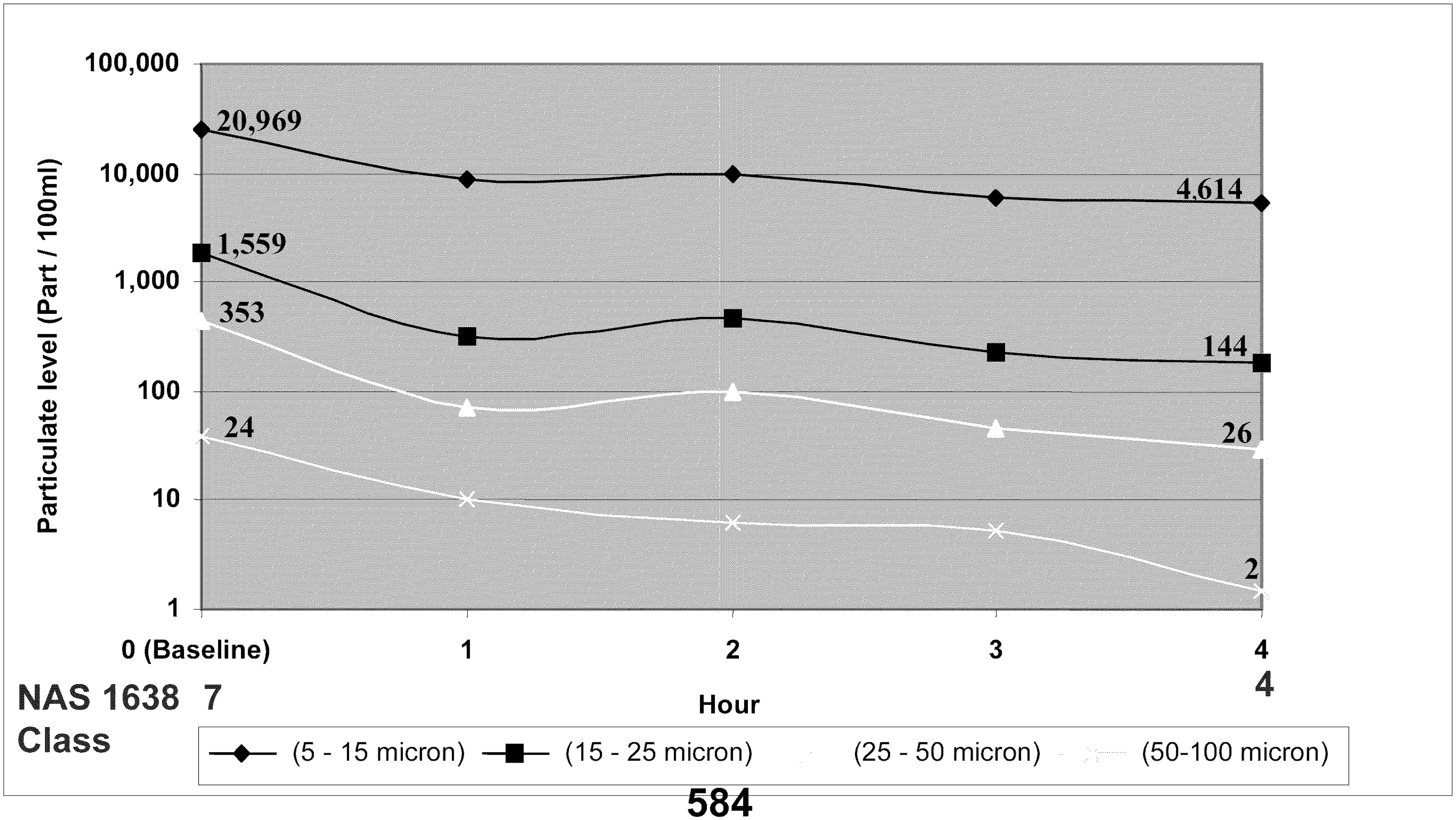
PPFP Water Removal

Average reduction for 4-hour purification events

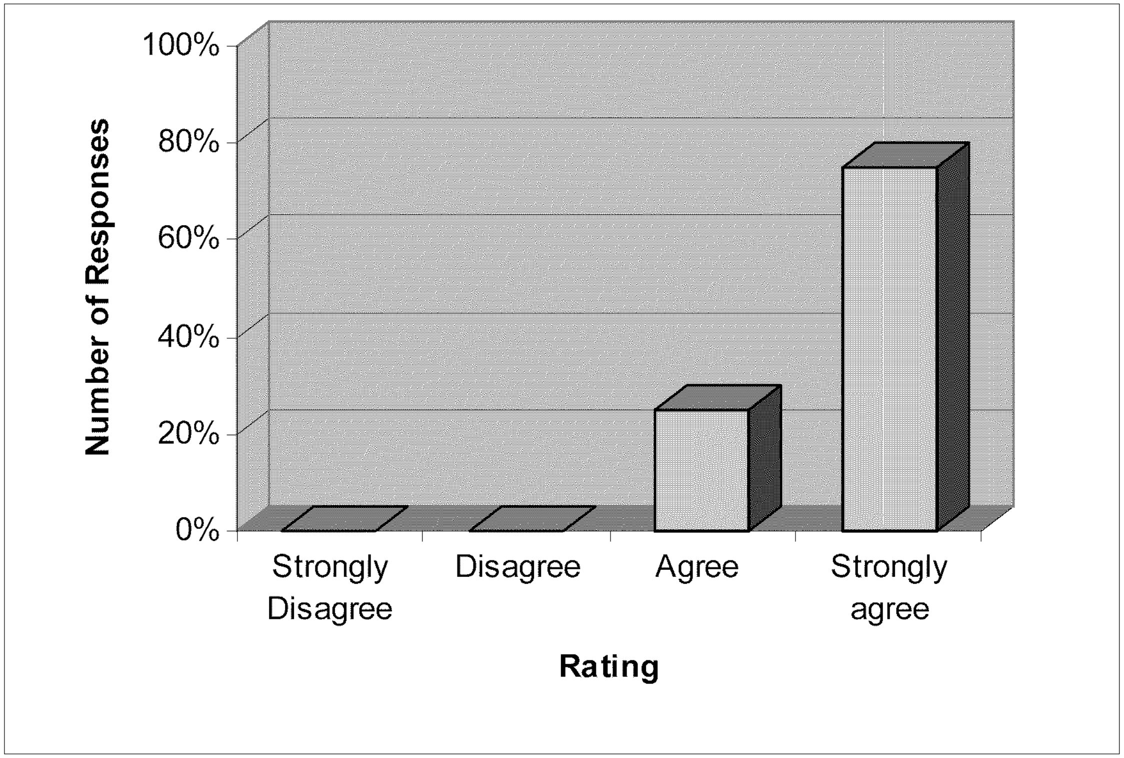


PPFP Particulate Removal

Average reduction for 4-hour purification events



PPFP Suitability
Set up/ teardown



Setup/Teardown

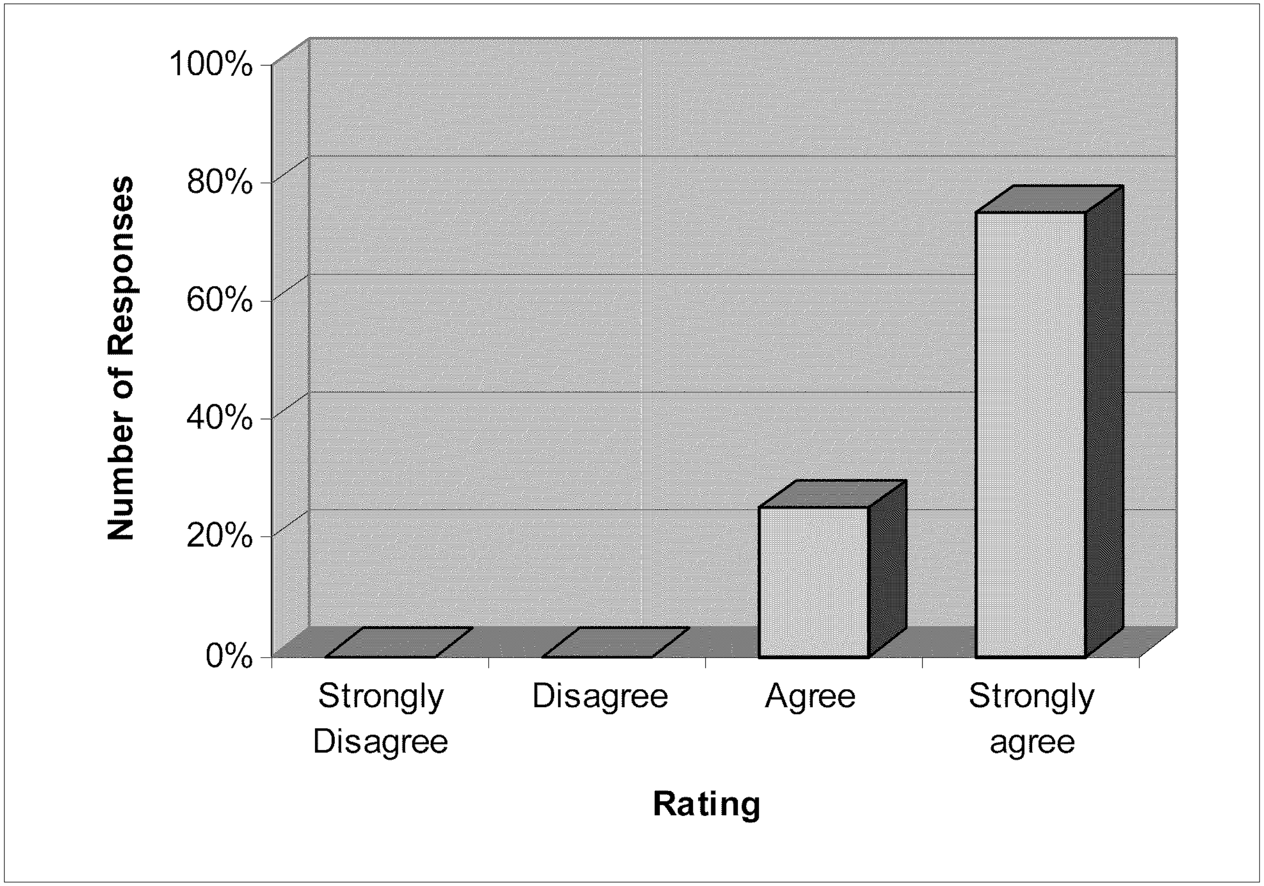
"Easy, clean, and fast"

"It was just as easy to teardown as it was to setup."

Warfighter

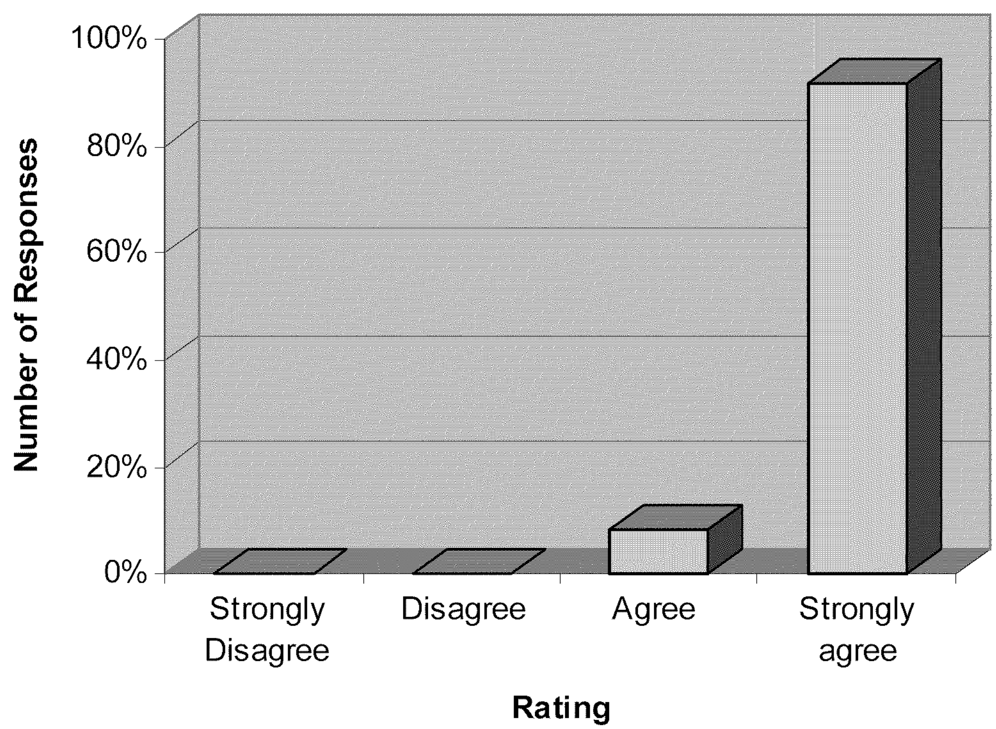
Setup/Teardown was easily accomplished:
Warfighters agreed the setup/teardown of the PPFP was easily accomplished with only a few tools and no special equipment

PPFP Suitability
Interoperability



Interoperability: Warfighters agreed the PPFP and mule were interoperable

PPFP Suitability
Ease of Use



Ease of Use: Warfighters agreed the PPFP is very easy to use.

Ease of Use

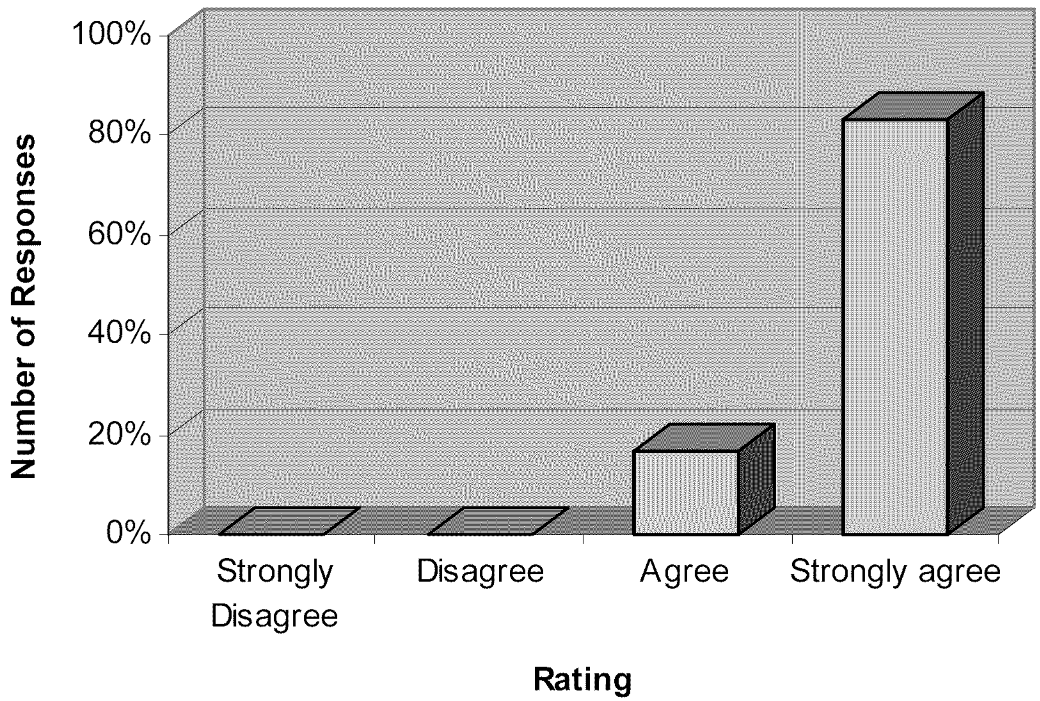
"Nice layout, easy to use."

"Anybody could run this, it is very simple."

"The only [thing] I would change is a way to test the fault lights prior to operation."

Warfighter

PPFP Suitability
Unit Impact



Unit Impact

"Saves manpower!"

"Unit is self contained and requires little or no standby assistance"

Warfighter

Unit impact: Warfighters agreed the PPFP would not increase manpower requirements

PPFP Suitability
Training

Training: Warfighters agreed the training was not excessive and provided them with enough knowledge to operate the PPFP

Training

"Instructions were appropriate for operating the unit. Easy to follow instructions without complicated details to remember."

Warfighter

ANALYTICAL DATA ON AIRCRAFT AND MULE HYDRAULIC FLUID SAMPLES

George Fultz

AFRL/MLBT/UDRI

Hydraulic Fluid Sampling Program

- Objective: Analyze hydraulic fluid from operational aircraft and hydraulic test stands (mules) for particulate, water and chlorinated solvent contamination

- Primary purpose is to develop a realistic standard for maximum contamination levels in operational hydraulic systems

- This will serve as a guideline for establishing cleanliness standards for hydraulic fluid purification for both servicing equipment as well as aircraft

- Only current standard is for new hydraulic fluid – not realistic for in-use hydraulic fluid

Aircraft/Mules to Sample

MDS	# of AIRCRAFT	SYSTEMS per ACFT	TOTAL SAMPLES per ACFT	MULE Samples	TOTAL SAMPLES per BASE	# of BASES	TOTAL SAMPLES for MDS
A-10	4	2	8	4	12	4	**48**
B-1	6	4	24	4	28	2	**56**
B-2	2	4	8	4	12	2	**24**
C-130	4	3	12	4	16	7	**112**
C-17	4	4	16	4	20	3	**60**
C-5	4	4	16	4	20	4	**80**
F/A-22	2	2	4	2	6	3	**18**
F-15	4	3	12	4	16	6	**96**
F-16	4	2	8	4	12	8	**96**
KC-135	4	2	8	4	12	6	**72**
MH-53	4	3	12	4	16	4	**64**
U-2	3	1	3	4	7	2	**14**
TOTALS	**45**		**131 592**	**46**	**177**	**51**	**740**

UP TO DATE SAMPLE COUNT

AIRCRAFT

Kits For Program	570
Kits Sent Out	502
Kits Received and Analyzed	291
Kits Needing Address	68 (5 Bases)

MULES

Kits For Program	213
Kits Sent Out	189
Kits Received and Analyzed	147
Kits Needing Address	24 (6 Bases)

DATA DETERMINED ON EACH SAMPLE

- PARTICULATE COUNT
  FTM 791C 3012
- WATER CONTENT
  ASTM D 6304
- BARIUM CONTENT
  ASTM D 5185
- CHLORINE
  CAPILLARY GC

PARTICULATE COUNT BY AUTOMATIC PARTICLE COUNTER

Calibrated by Manufacturer Every Six Months

NAS 1638

MAXIMUM CONTAMINATION LEVEL OF 100 ML SAMPLES

	Contamination Class						
Micron Range	**00**	**0**	**1**	**2**	**3**	**4**	**5**
5 -15	125	250	500	1,000	2,000	4,000	8,000
15 - 25	22	44	88	176	352	704	1,408
25 - 50	4	8	16	32	64	128	253
50 -100	1	2	3	6	11	22	45
>100	0	0	1	1	2	4	8

	Contamination Class						
Micron Range	**6**	**7**	**8**	**9**	[redacted]	[redacted]	[redacted]
5 -15	16,000	32,000	64,000	12,800	256,000	512,000	1,024,000
15 - 25	2,816	5,632	11,264	22,528	45,056	90,112	180,224
25 - 50	506	1,012	2,025	4,050	8,100	16,200	32,400
50 -100	90	180	360	720	1,440	2,800	5,600
>100	16	32	64	128	256	512	1,024

WATER CONTENT

REASONABLE LIMIT LESS THAN 300 PPM

BARIUM CONTENT BY ICP

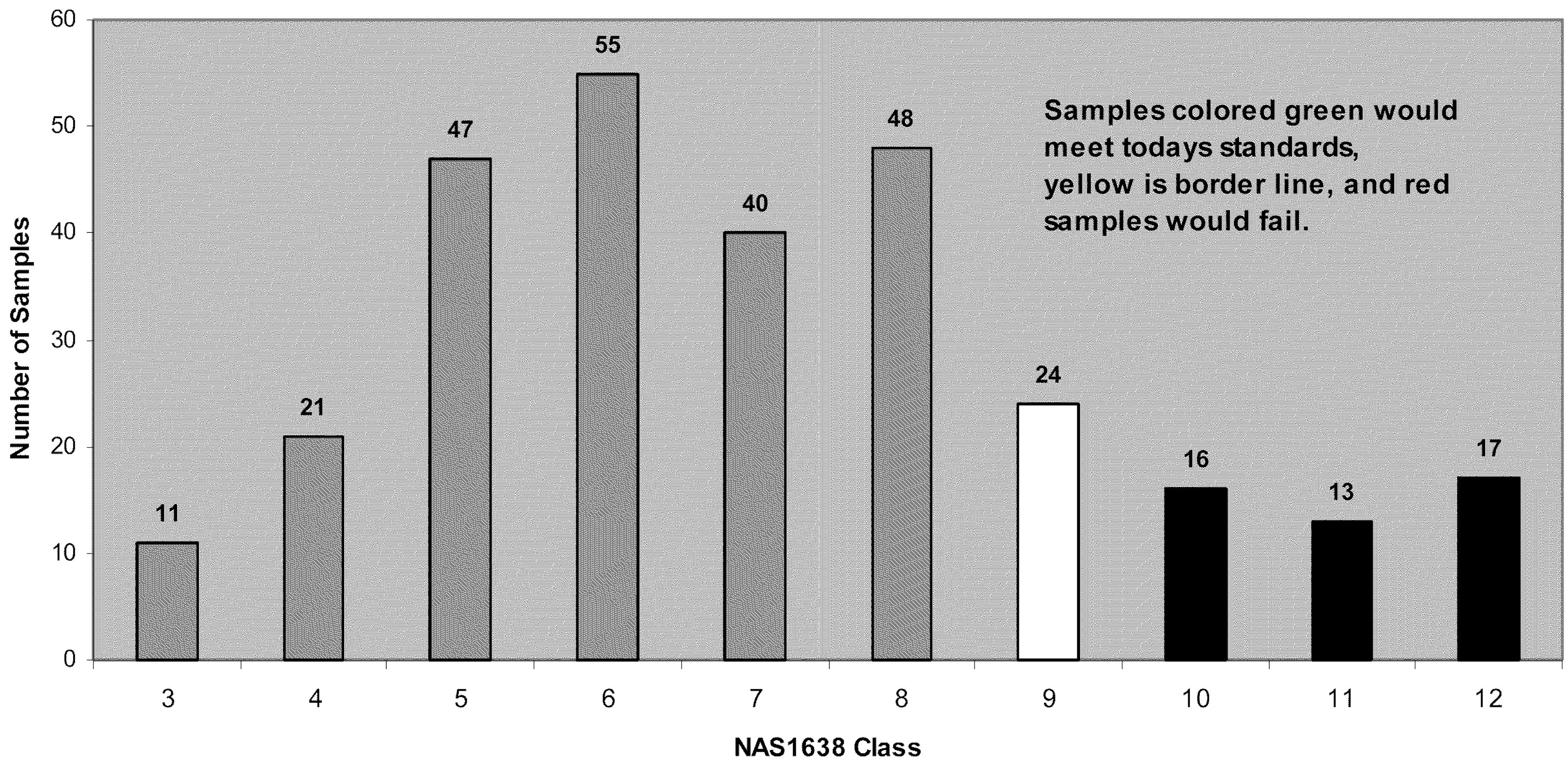
REASONABLE LIMIT LESS THAN 20 PPM

CHLORINE BY GAS CHROMATOGRAPHY

REASONABLE LIMIT LESS THAN 200 PPM

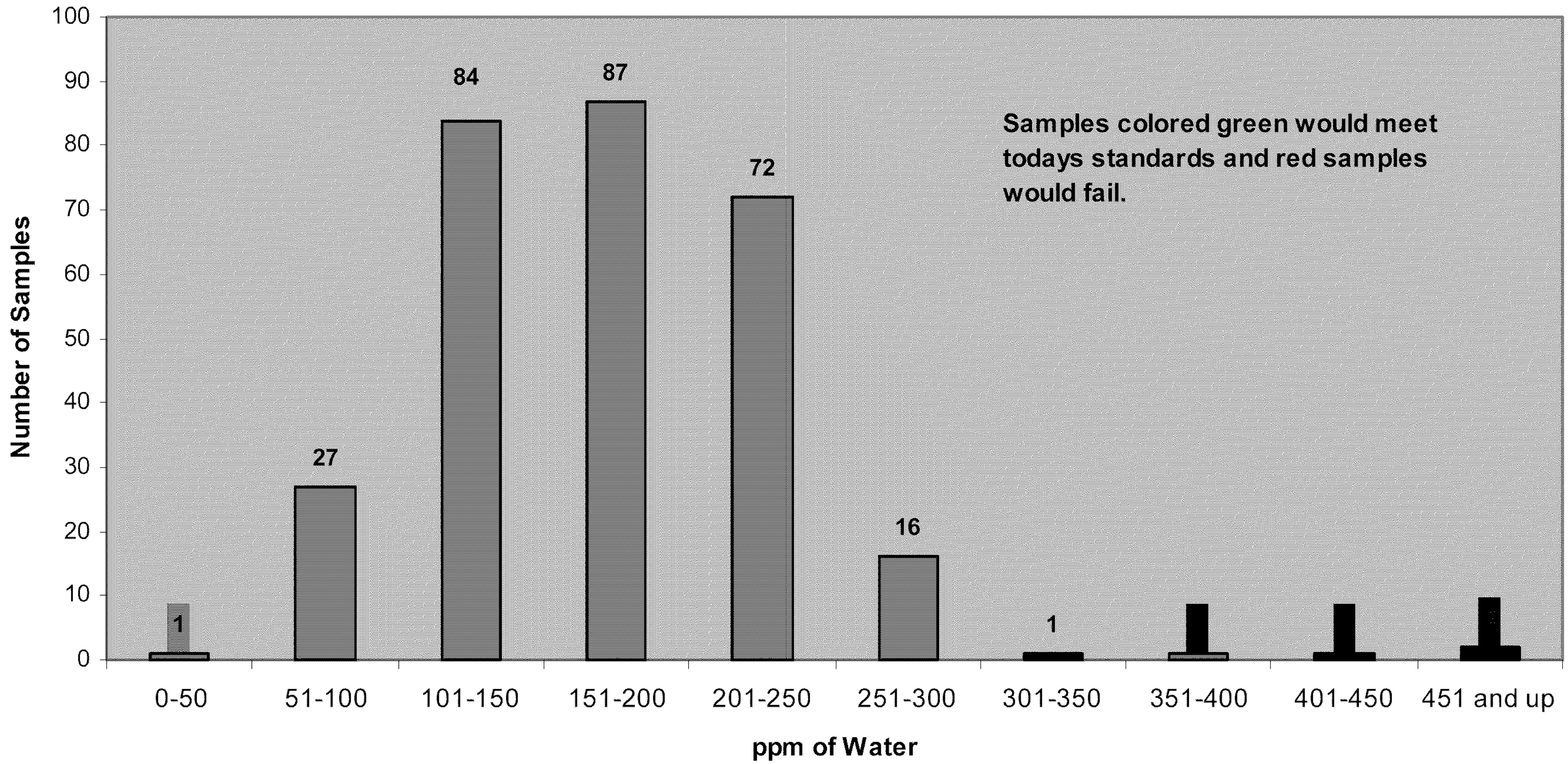
All Aircraft Particulate Contamination Data

June 14, 2004



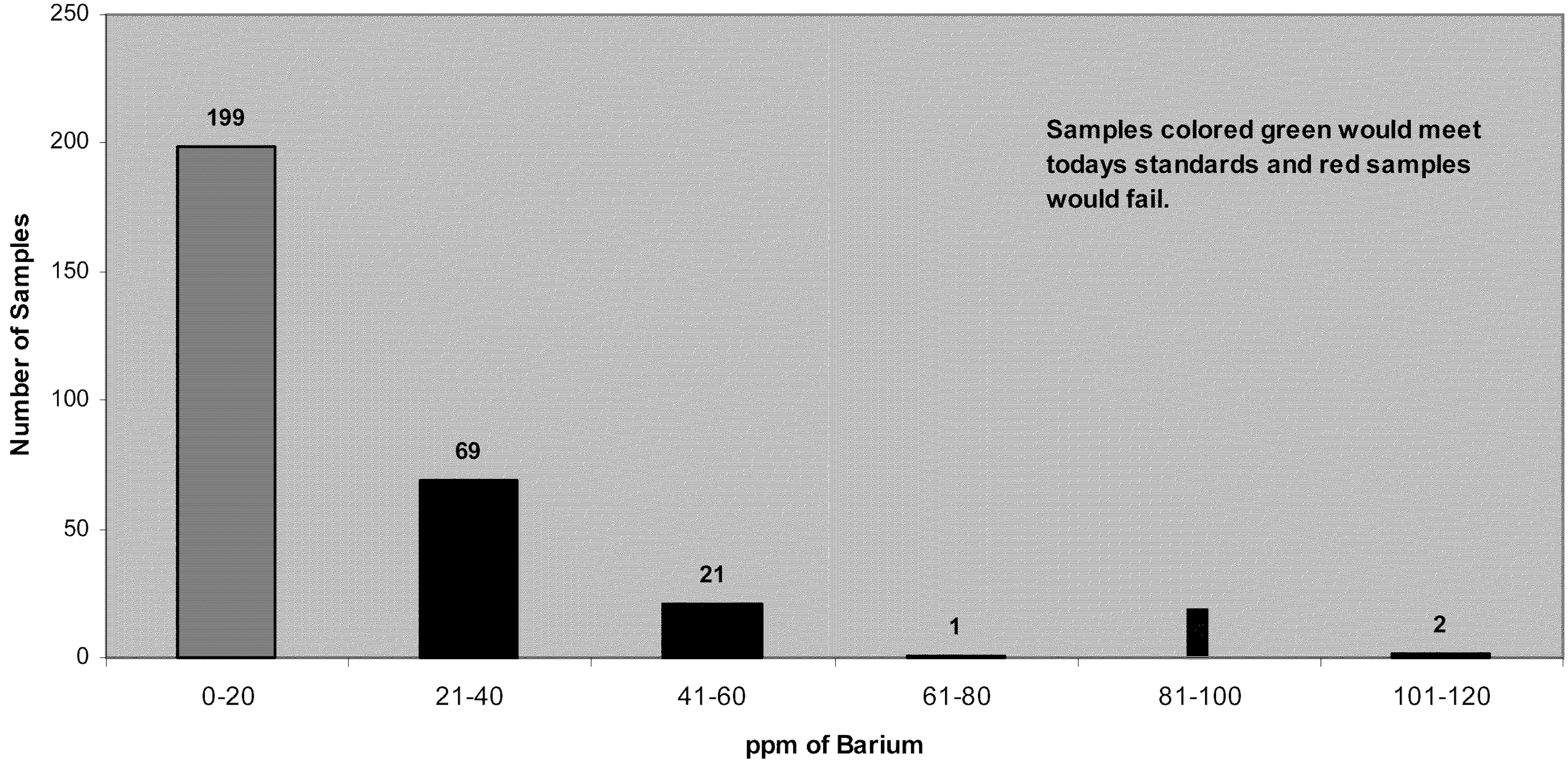
All Aircraft Water Content Data

June 14, 2004

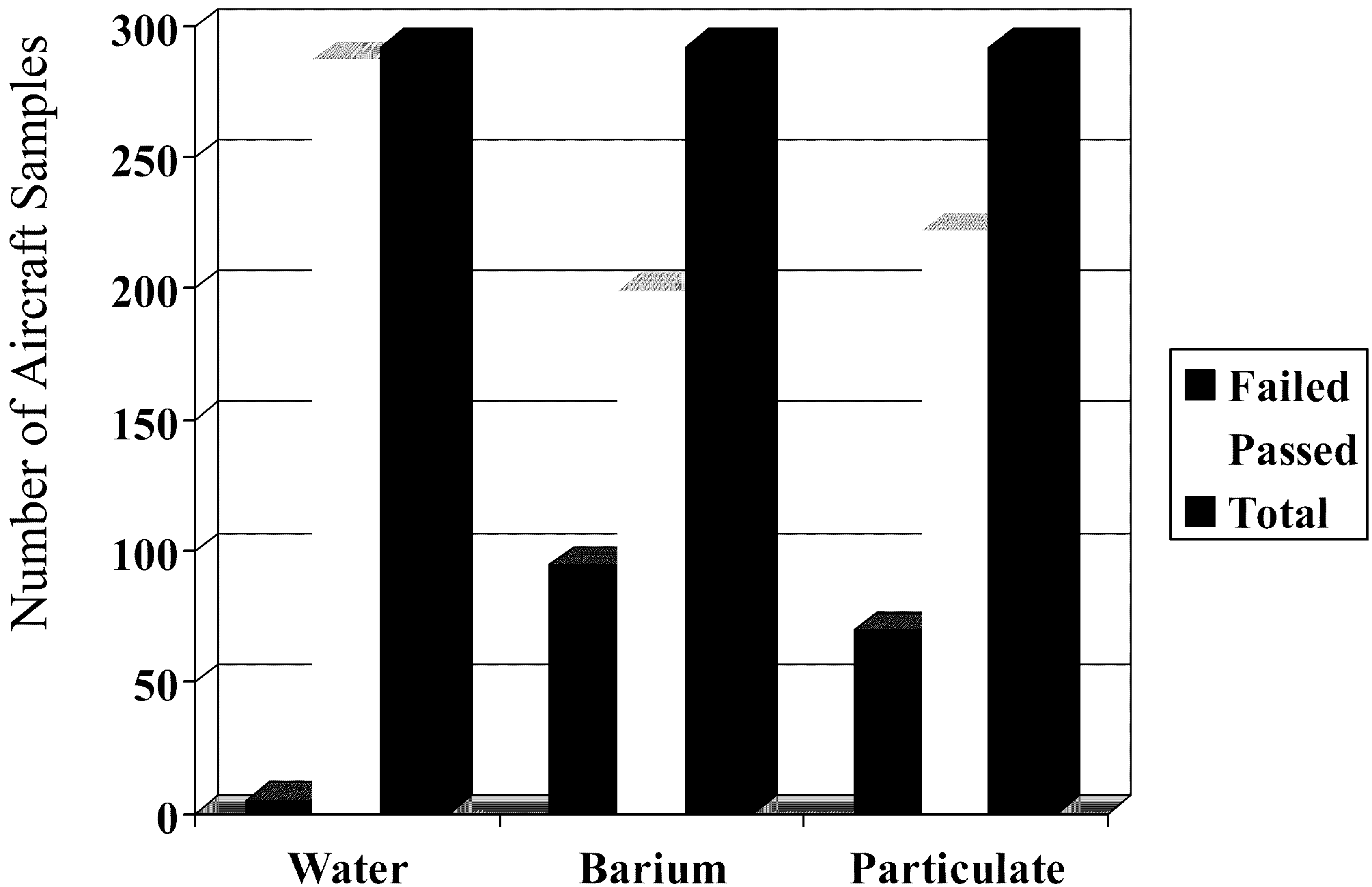


All Aircraft Barium Content Data

June 14, 2004



Aircraft Samples Using Previous Described Limits



All Mule Particulate Contamination Data

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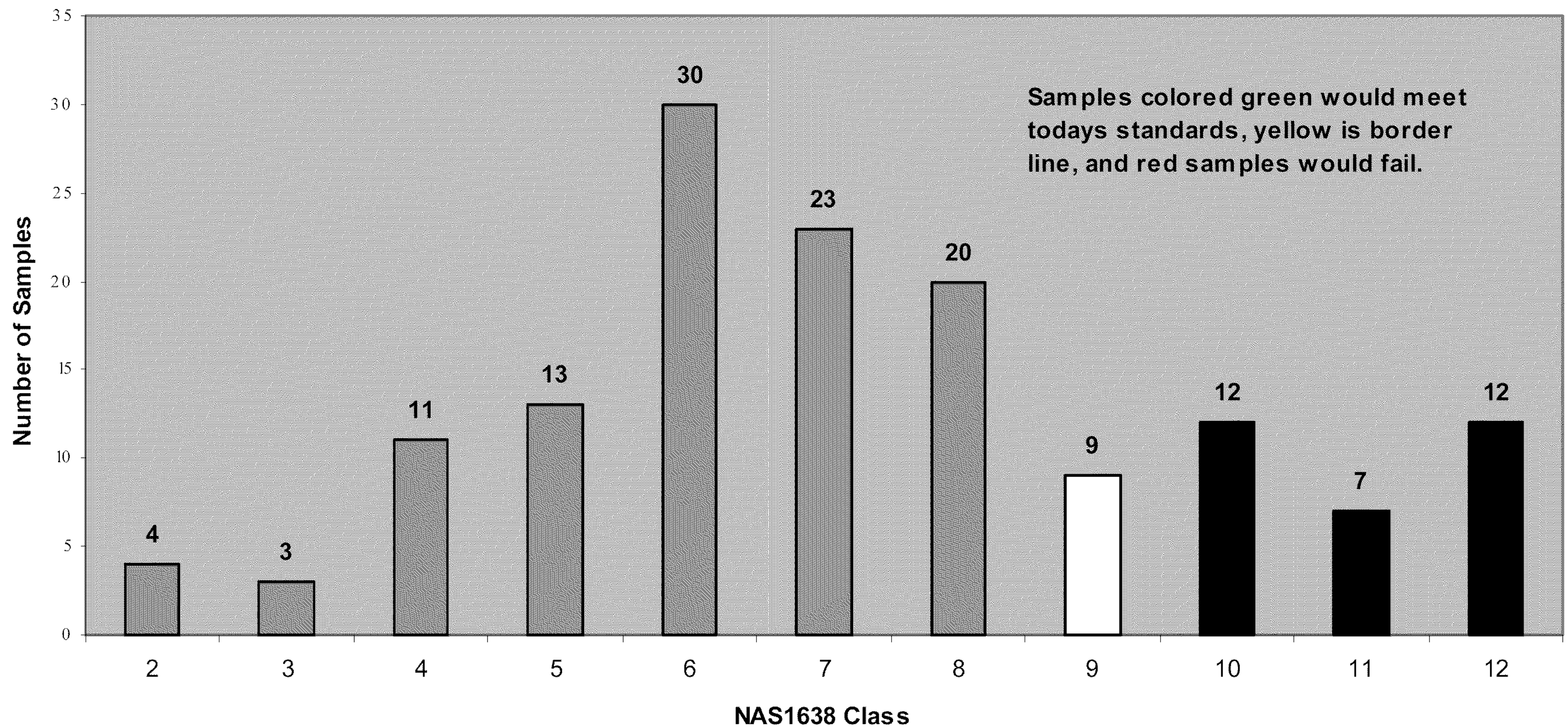
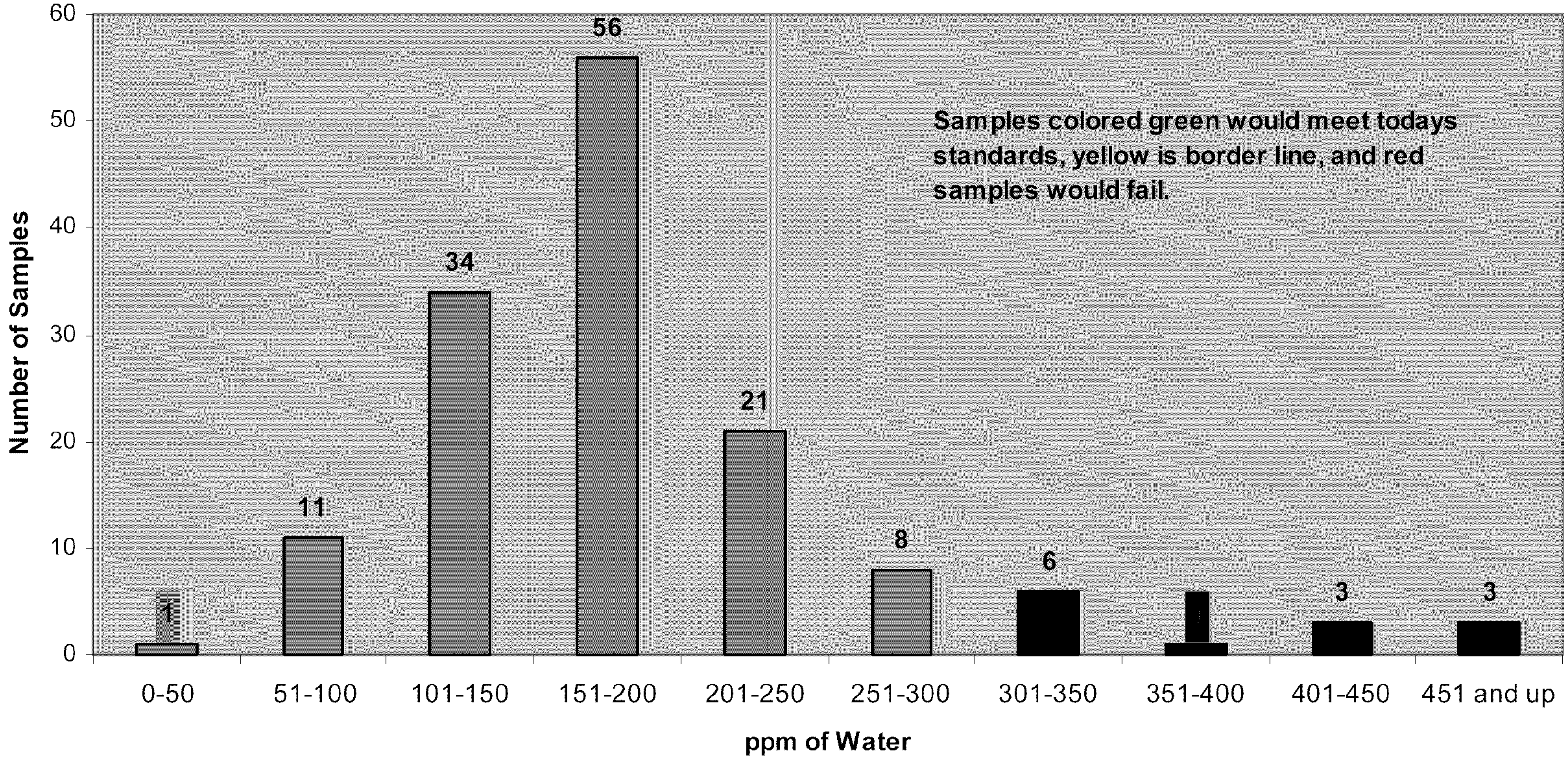


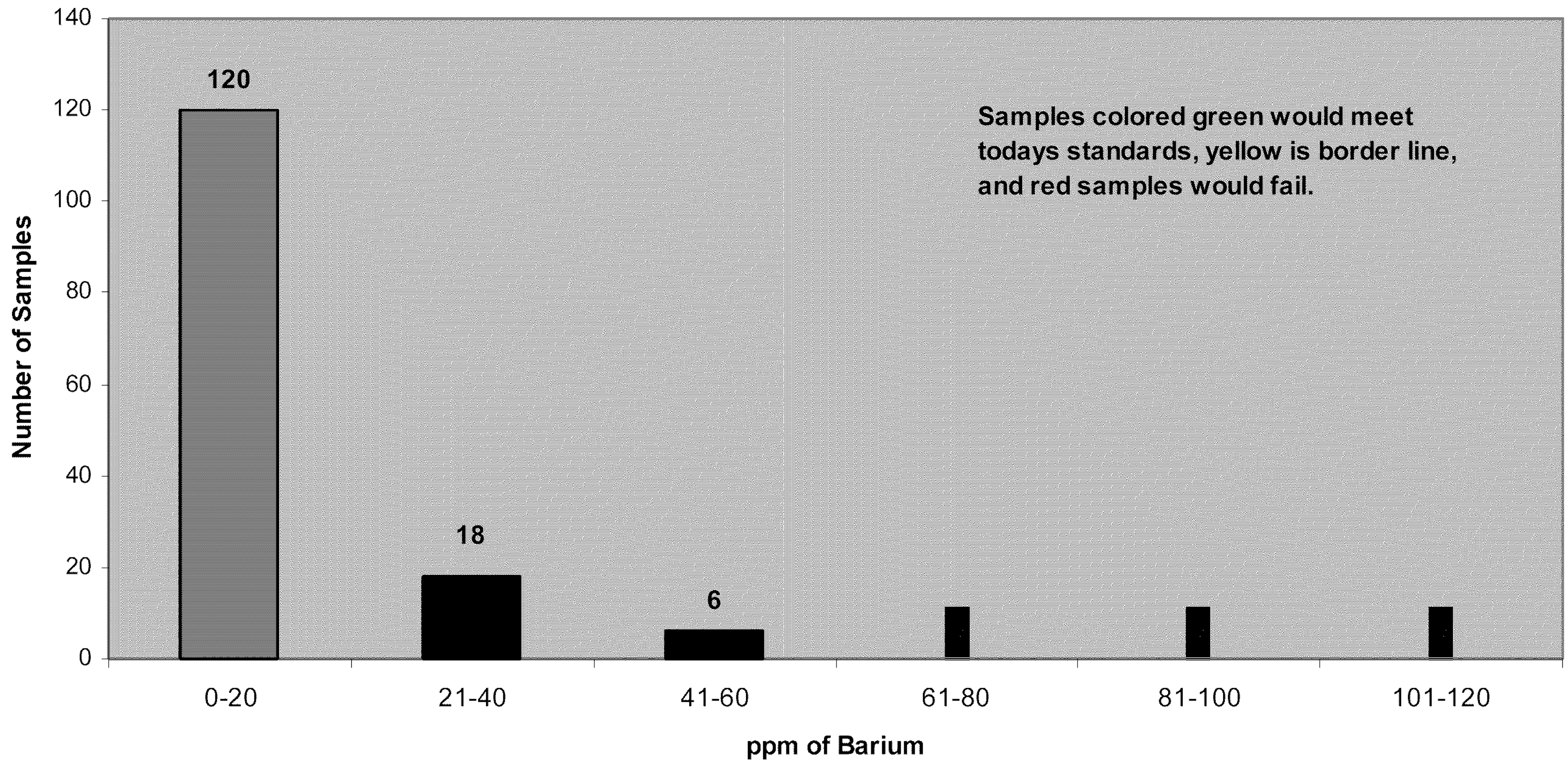
All Mule Water Content Data

June 14, 2004

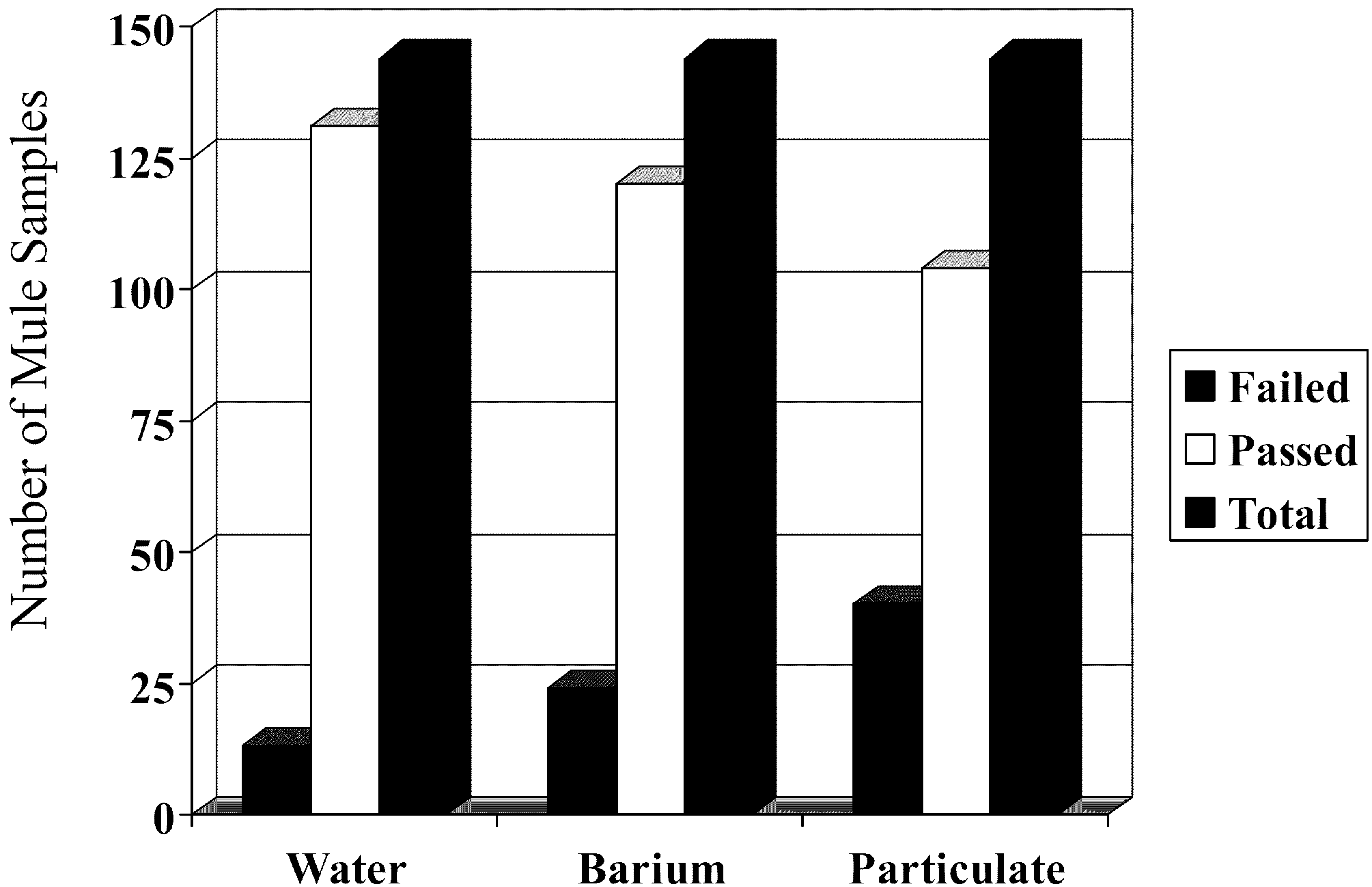


All Mule Barium Content Data

June 14, 2004



Mule Samples Using Previous Described Limits



Summary

- First broad range A/C and mule sampling program
- Data should be completed in a few months if addresses are received and kits mailed
- When completed - enough data for meaningful statistics
- Establishes baseline for future purification work

Effect of Purification on Fluid Properties and Performance

Shashi Sharma
Ed Snyder
Lois Gschwender
Air Force Research Laboratory
Wright Patterson AFB, OH

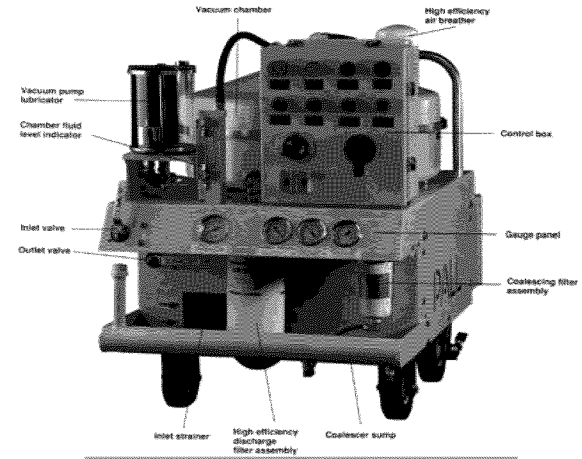
Timothy Jenney
George Fultz
University of Dayton Research Institute,
Dayton OH

Outline

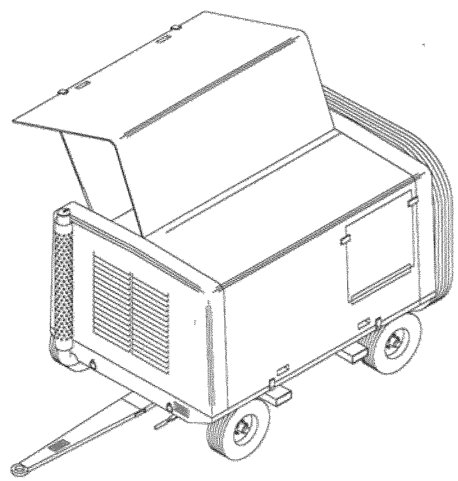
- Background
  - Purification process
  - Performance evaluation of purified fluid in pump tests
- Effect of Purification on Fluid Properties and Performance
  - Pump tests with MIL-PRF-5606
  - Pump tests with MIL-PRF-83282
  - Pump Tests with Malabar purifier
- Summary

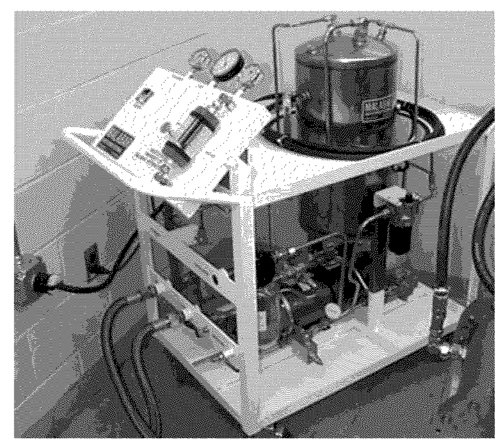
Purification Process

- **How the purifiers work:**
  - Create large fluid surface area using a spinning disk or by misting
  - Partial vacuum to remove volatiles
  - High efficiency fine filter
  - Some use absorption/adsorption to remove water
- **Effective in removing**
  - Particulate Contamination
  - Moisture
  - Solvents
  - **Air (Entrained and Dissolved)**
    - Spongy flight controls
    - Pump cavitation
    - Fluid over-temp
- **Portable and built-in configurations**



Pall Portable Purifier

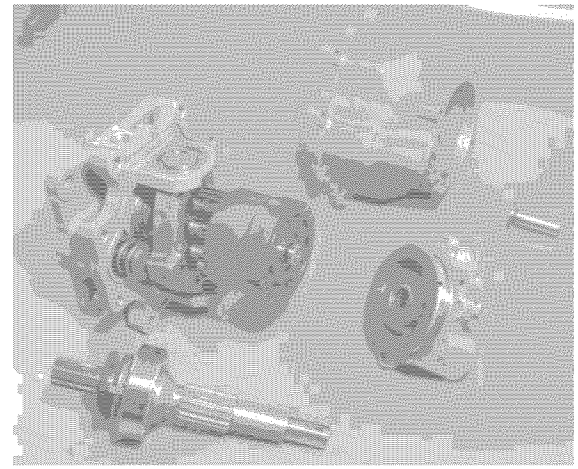


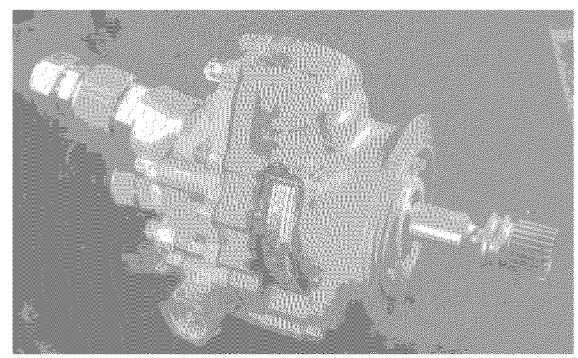


Malabar Ground Test Stand with Built-in Purifier

Performance Evaluation of Purified Fluid in Pump Tests

- In conjunction with SPOs and potential users MLBT developed a test protocol for extended hydraulic pump testing with repeatedly purified hydraulic fluid to answer this question
- Hydraulic pump most demanding component for fluid properties.
  - Rotating, sliding, oscillating metal on metal contacts
  - Highest temperature
  - Sensitive to foaming





Performance Evaluation of Purified Fluid in Pump Tests

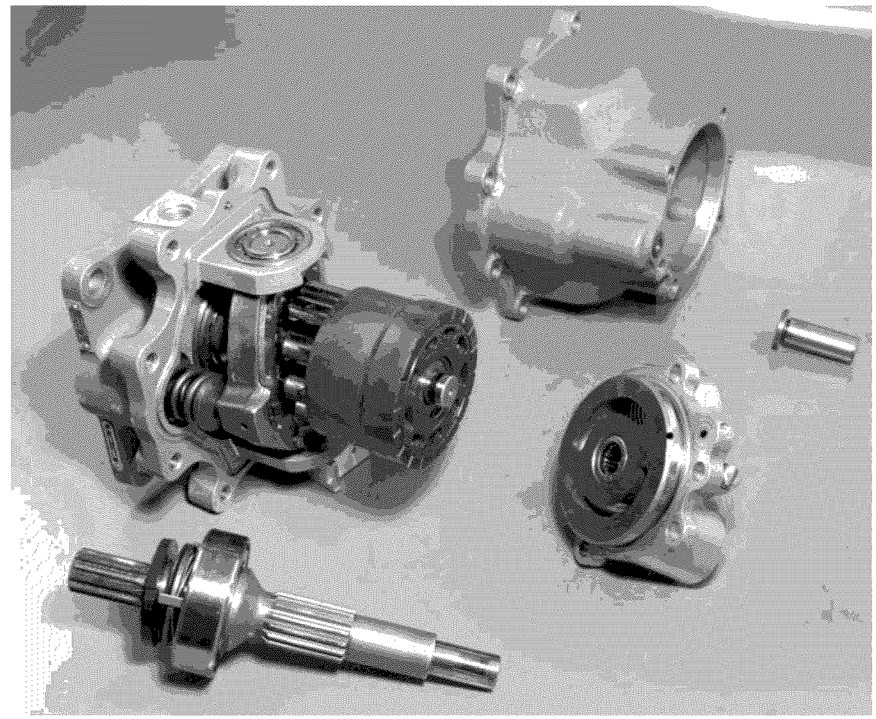
Lubrication Regimes in a Hyd. Pump

Boundary Lubrication

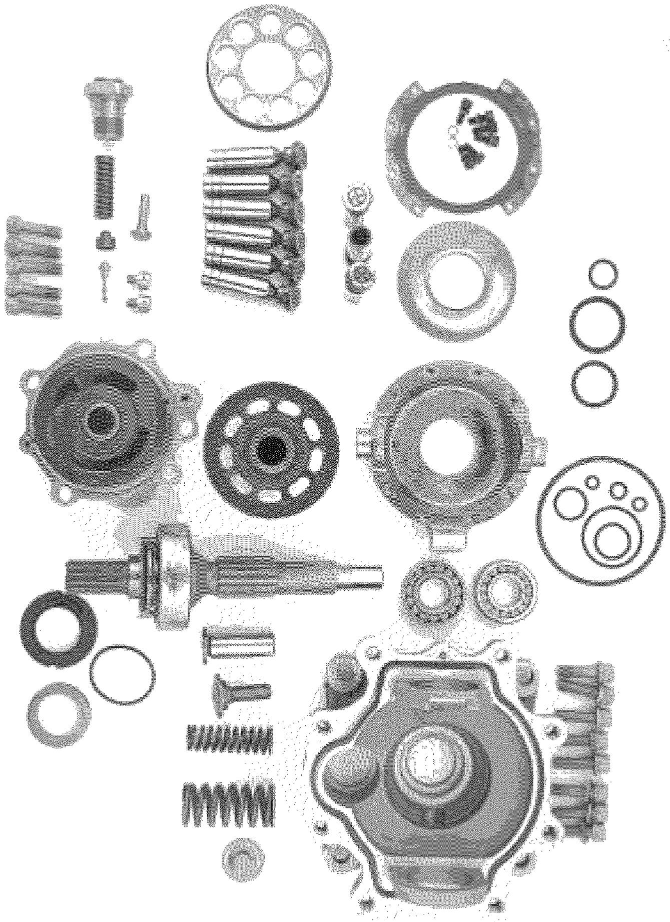
- Gross metal-metal contact
- Lower entraining speeds
- **Influenced by the fluid chemistry and surface properties**
- Anti-wear additives and surface modifications help

Fluid Film Lubrication

- Film thickness large compared to surface roughness
- No (or rare) metal-metal contacts
- Film thickness and power losses affected by
  - **Viscosity of the lubricant**
  - Pressure-viscosity effects



Performance Evaluation of Purified Fluid in Pump Tests



Surfaces under Boundary Lubrication

- Actuator Piston
- Shaft and Splines
- Pintle Bearings

Following Interfaces at Slower Speeds

- Cylinder Block and Valve Plate Faces
- Piston Shoe Faces and Piston;
- Pistons and Cylinder Bores
- Hold Down Plate and Bearing Plate
- Main Thrust Ball Bearing and Needle Bearing

Surfaces under Fluid Film Lubrication

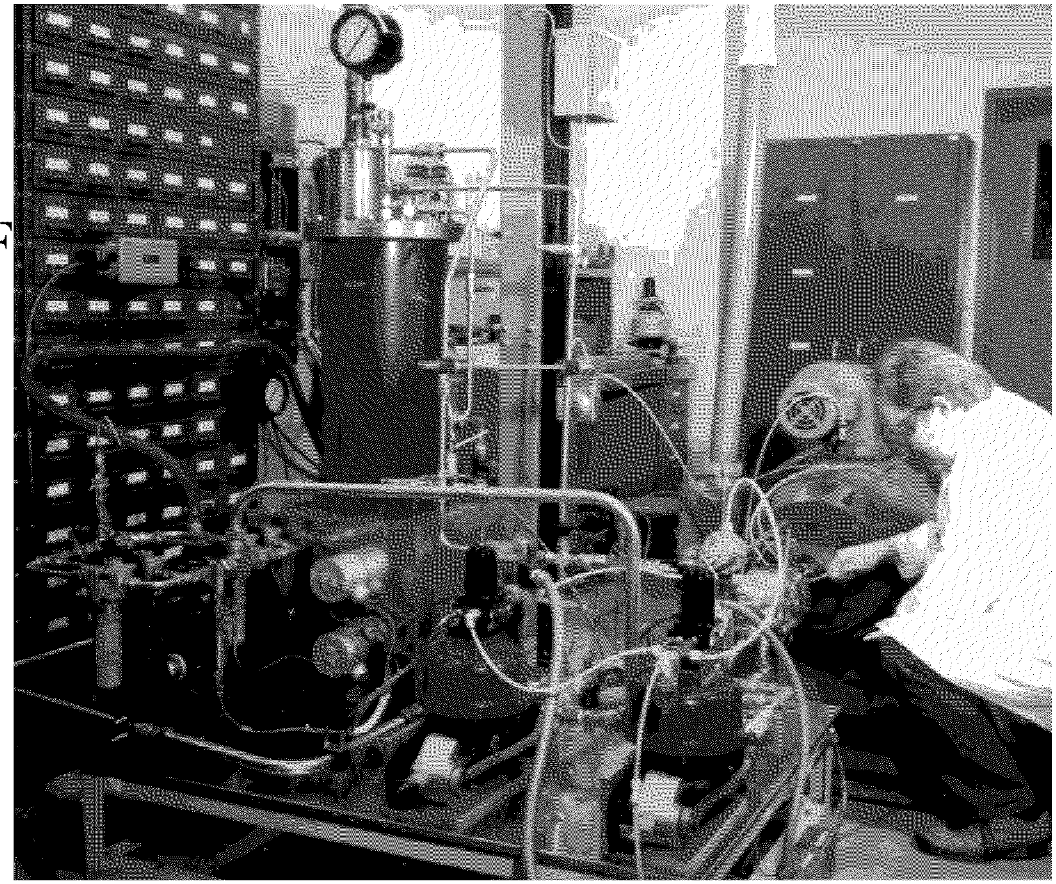
Following Interfaces at Higher Speeds

- Piston Shoe Ball Joints
- Cylinder Block and Valve Plate Faces
- Piston Shoe Faces and Piston
- Pistons and Cylinder Bores
- Hold Down Plate and Bearing Plate
- Main Thrust Ball Bearing and Needle Bearing

Performance Evaluation of Purified Fluid in Pump Tests

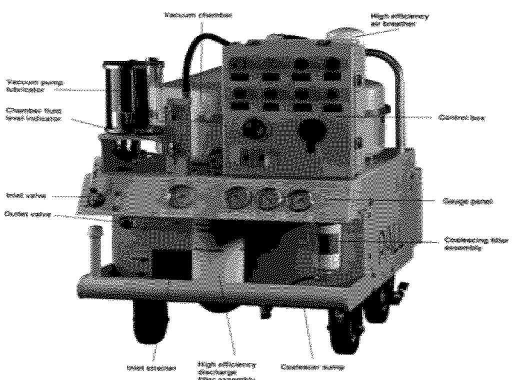
MLBT Pump Test Stand

- All stainless steel
- Capable of 8000 psig and 350°F
- Test loop volume 1-15 gallon
- Well instrumented



Fluid Purifier

- Pall Model PE-00440-1H



Performance Evaluation of Purified Fluid in Pump Tests

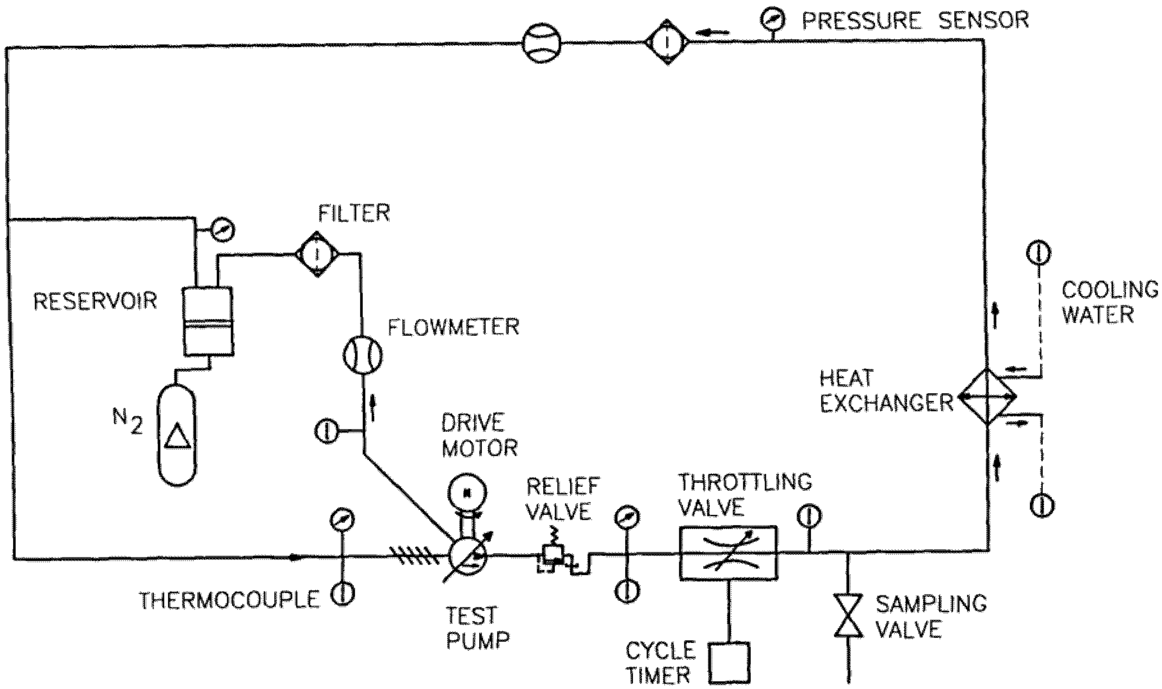


FIGURE 1: HYDRAULIC PUMP TEST CIRCUIT

Analyses of Fluid Samples

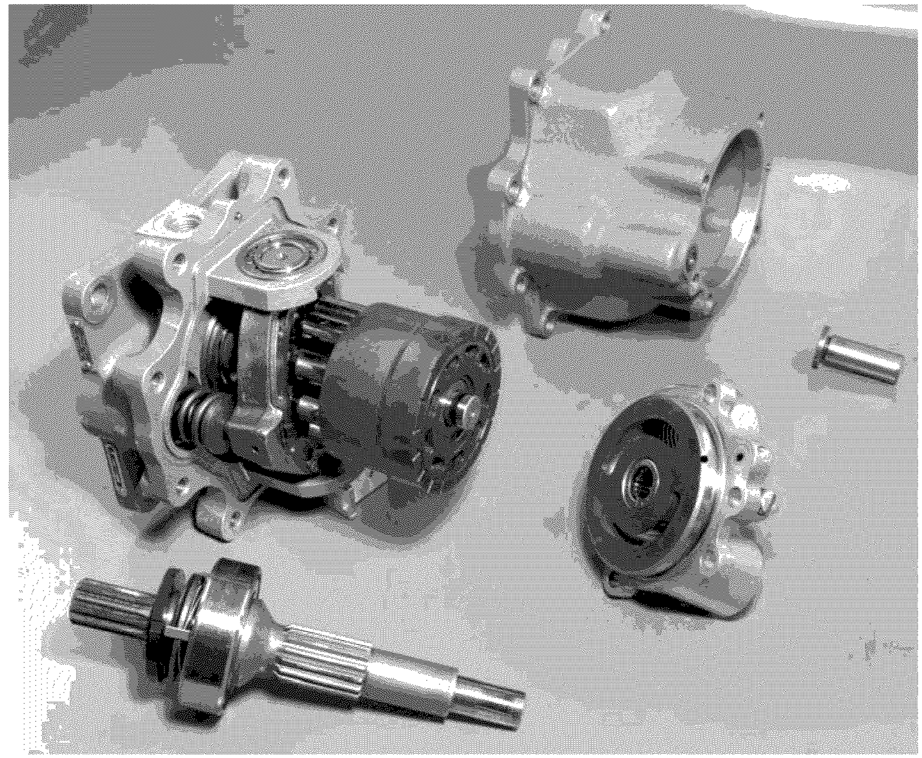
- **Viscosity**
- **Water Content**
- **Lubricity (4 Ball Wear Test)**
- **Foaming**
- **Metal Analysis**
- **Gas Chromatography**
- **Dissolved Air**

Pump tests with MIL-PRF-5606

Test Plan

Test 1: Base Line with Fresh MIL-H-5606

- Vickers Pump PV3-075-15
- 1000 hours inspection
- 1500 hours or performance degradation
- 5000 rpm, 3000 psig, 255°F max fluid temp
- Flow cycled between 12 and 3 gpm every minute
- Periodic fluid samples



Test 2: Test with Purified MIL-H-5606

- Same as Test 1 Except Fluid Purification
- Fluid Purified Every 200 Hours, using Pall purifier

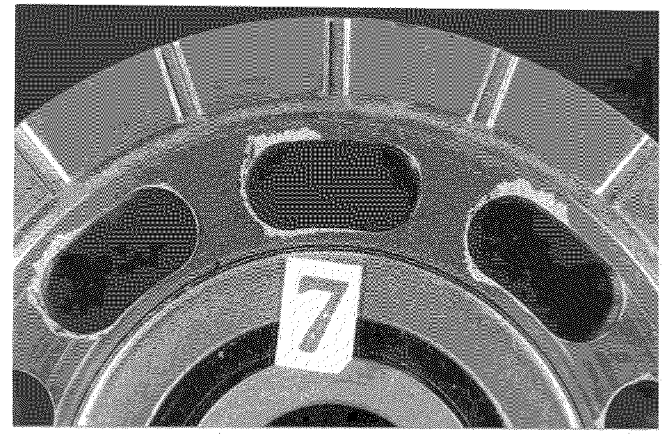
Pump tests with MIL-PRF-5606

Test Results

- 1500 hour pump tests completed with
  - Fresh MIL-H-5606 and
  - Purified MIL-H-5606
- No significant difference between the two tests
- No fluid property changes except for loss in viscosity

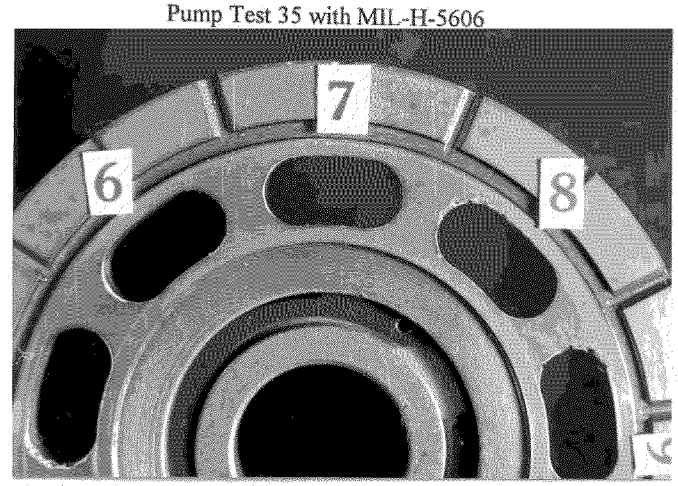
✓Pall purifier use will not decrease Pump Life or affect fluid properties

- "Endurance Pump Tests with Fresh and Purified MIL-H-5606 Hydraulic Fluid," AFRL-ML-WP-TR-1998-4211



Enlargement of Cylinder Block Face

Cylinder Block Faces after 1500 Hours
Pump Test 35 with MIL-H-5606



Cylinder Block Face 6,7,8

Cylinder Block Face after 1500 hrs.
Pump Test 36 with MIL-H-5606

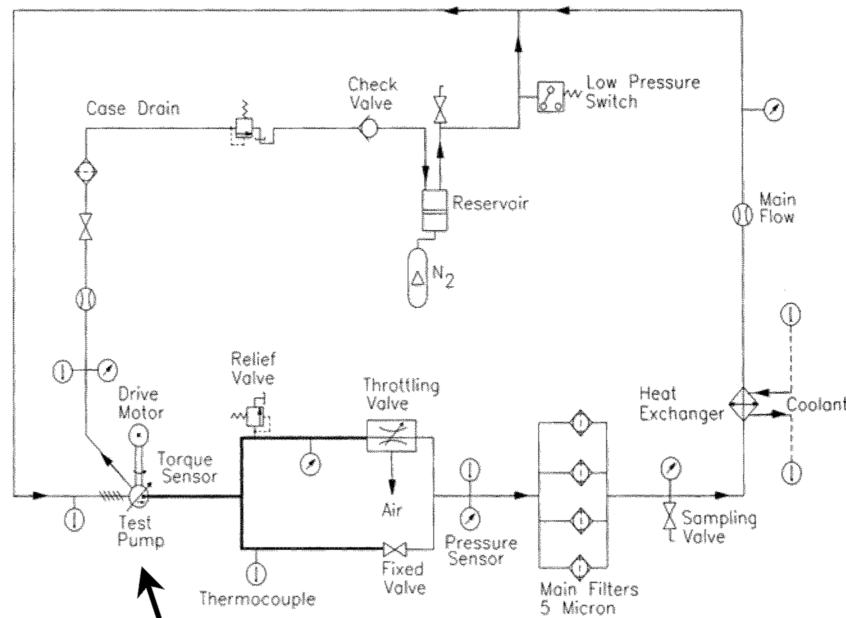
Outline

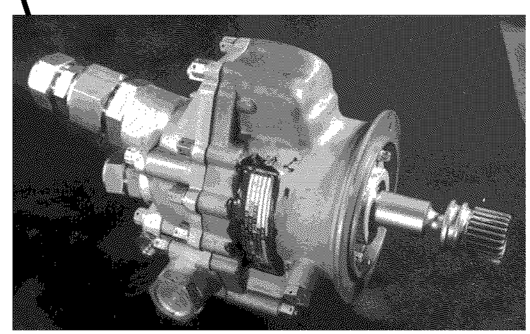
- Background
  - Purification process
  - Performance evaluation of purified fluid in pump tests
- Effect of Purification on Fluid Properties and Performance
  - Pump tests with MIL-PRF-5606
  - Pump tests with MIL-PRF-83282
  - Pump Tests with Malabar purifier
- Summary

Pump tests with MIL-PRF-83282

Test Plan

- Test 1: Base line with fresh MIL-PRF-83282
  - Abex Pump AP12V-17 (F-16 main pump)
  - 1000 Hr inspection
  - 300 ppm water in test fluid, after 1000 hrs
  - 2000 hours or performance degradation
  - 5000 rpm, 3100 psig, 255°F max fluid temp
  - Flow cycled between 28 gpm and 36 gpm every minute
  - Periodic fluid samples
- Test 2: Test with purified MIL-PRF-83282
  - Same as Test 1 except fluid purification
  - Fluid purified using Pall purifier every 300 hrs





Pump tests with MIL-PRF-83282

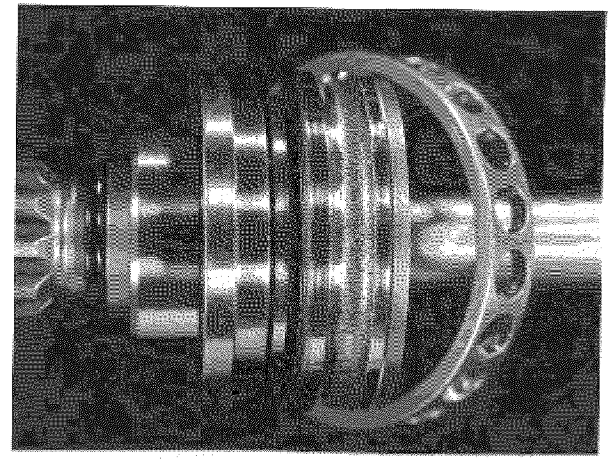
Test Results

- Test 1: Base line with fresh MIL-PRF-83282
  - Completed 1343 hours
  - High case-drain temperature
  - Excessive wear on the barrel roller bearing

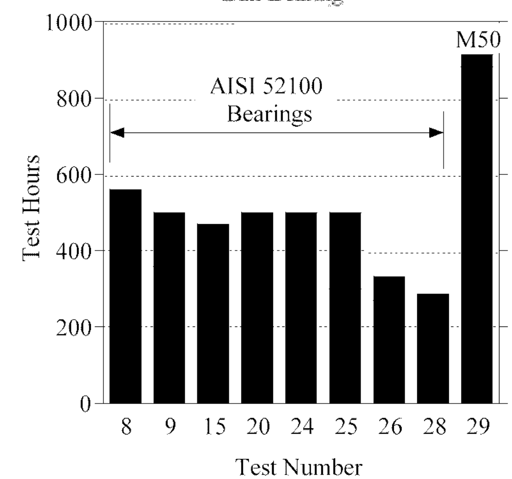
- Test 2: Test with purified MIL-PRF-83282
  - Completed 1513 hours
  - High case-drain temperature
  - Excessive wear on the barrel roller bearing and the ball bearing
- No significant difference between the two tests
  - Bearing failures similar to the field failures
  - 52100 steel bearings are the weak link
  - F-16 has converted to M50 bearing steel

✓ No changes in fluid properties

✓ Pall purifier use will not decrease F-16 pump life



Ball Bearing



Onset of Bearing Failure in CTFE Pump Tests

"Endurance Pump Tests with Fresh and Purified MIL-PRF-83282 Hydraulic Fluid,"

AFRL-ML-WP-TR-1999-4185

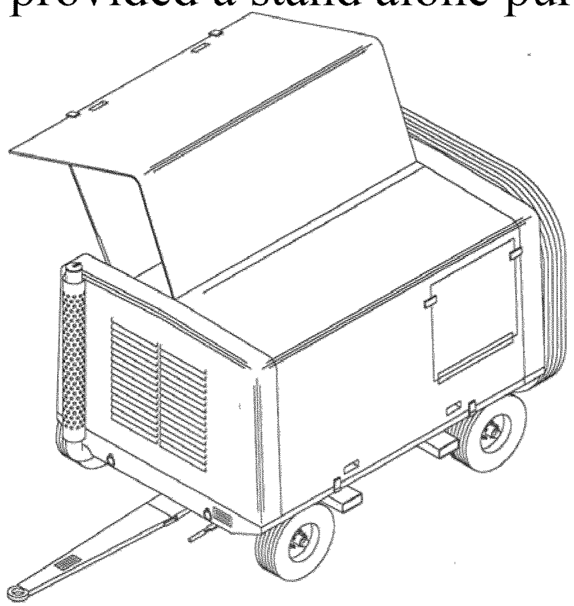
Outline

- Background
  - Purification process
  - Performance evaluation of purified fluid in pump tests
- Effect of Purification on Fluid Properties and Performance
  - Pump tests with MIL-PRF-5606
  - Pump tests with MIL-PRF-83282
  - Pump Tests with Malabar purifier
- Summary

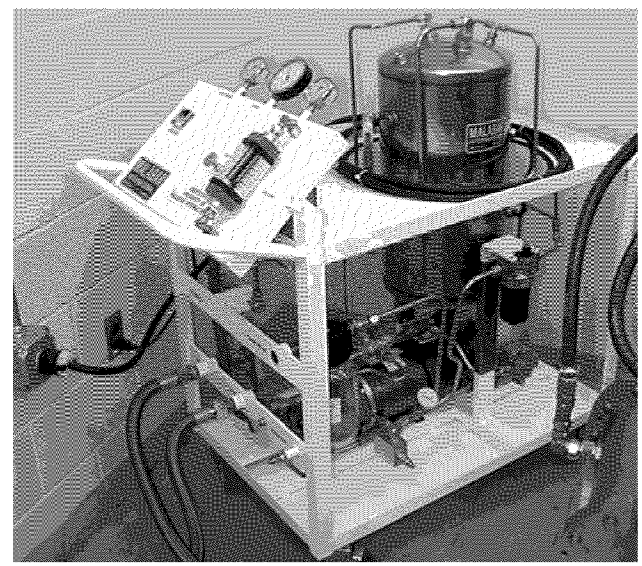
Pump tests with Malabar Purifier

ALC is procuring ~700 new hydraulic ground test stands from Malabar

- Based upon AFRL/MLBT work, ALC decided to incorporate purification in the new units
- Purifier different design than Pall's
- Effect of Malabar purifier on pump life unknown
- Aging Aircraft SPO and ALC (Warner Robbins) approached MLBT to conduct study
- Malabar provided a stand alone purifier for this work



Malabar Ground Test Stand



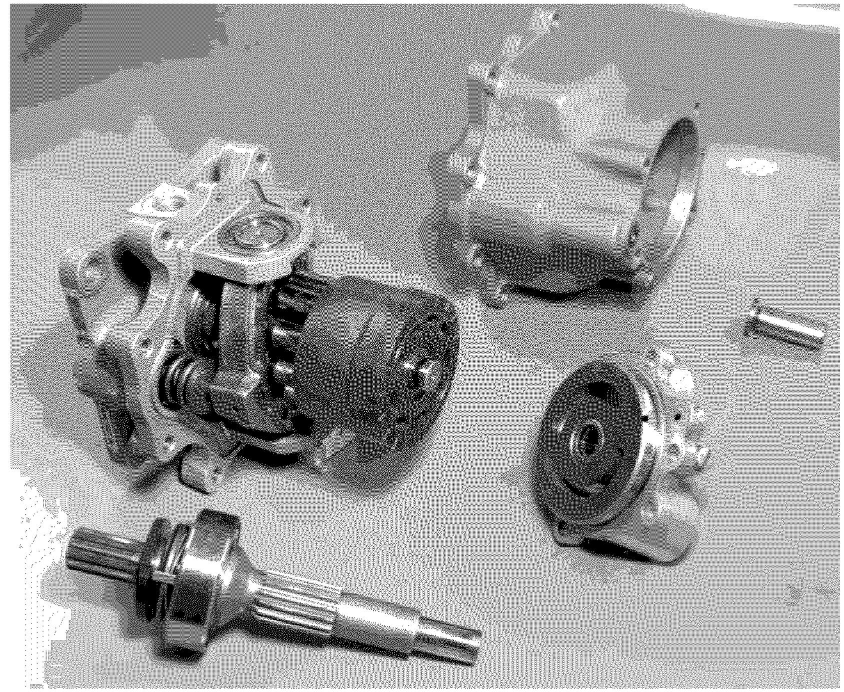
Malabar Purifier

Pump tests with Malabar Purifier

Test Plan

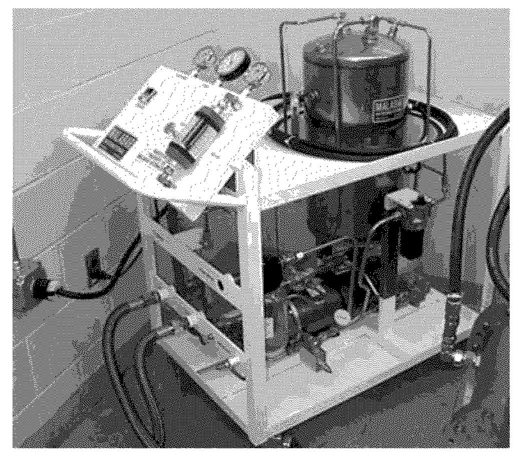
Test 1: Base Line with Fresh MIL-PRF-83282

- Vickers Pump PV3-075-15
- 1000 hours inspection
- 1500 hours or performance degradation
- 5000 rpm, 3000 psig, 255°F max fluid temp
- Flow cycled between 12 and 3 gpm every minute
- Periodic fluid samples



Test 2: Test with Purified MIL-PRF-83282

- Same as Test 1 Except Fluid Purification
- Fluid Purified Every 200 Hours, using Malabar purifier



•Test Results

- ✓ **No significant difference between the two tests**
- ✓ **No changes in fluid properties**
- ✓ **Malabar purifier will not adversely impact pump performance/life**

Effect of Purification on Fluid Properties and Performance

Summary

- Pall purifier tested with both MIL-PRF-5606 and MIL-PRF-83282
  - ✓No degradation of fluid performance resulting from purification
- Malabar purifier tested with MIL-PRF-83282
  - ✓No degradation of fluid performance resulting from purification
- At the conclusion of pump tests, both 5606 and 83282 met new fluid properties except for 5606 losing viscosity due to shearing in the pump test stand
  - ✓Shows that MIL-PRF-83282 does not "Wear out" and can be used for long periods of time in aircraft hydraulic systems

ACKNOWLEDGMENTS

- B2 SPO and ASC/SMA, $AVE for Funding the Pump Tests with MIL-H-5606
- Pump Tests with MIL-PRF-83282
  - OO-ALC Hill AFB for providing the funding for the Pump Tests
  - McClellan AFB for providing the test pumps and for helping with the disassembly and inspection of the piston-hanger assembly
- Eglin and Tyndall AFB for providing the Pall purifier
- Pall Corporation and Malabar International for supporting the test programs


BOEING 234 COLUMBIA
C

Hydraulic Purification

Bob Peterson

628

Hydraulic Purification

- Columbia Helicopters has been purifying the hydraulic systems of its 234 fleet for the past ten years.
- Beginning in 1995 we started testing the bearings of the hydraulic pumps and motors during overhaul.
  - In 1998 we started serializing the bearings to assist in fault analysis.

Hydraulic Purification

- We are finding that the wear and damage of the bearings has decreased as we maintain a NAS class 2 or 3.
- This has lowered our maintenance cost on the hydraulic pumps and motors.

Hydraulic Purification

REPEAT SERIAL NUMBER CHART